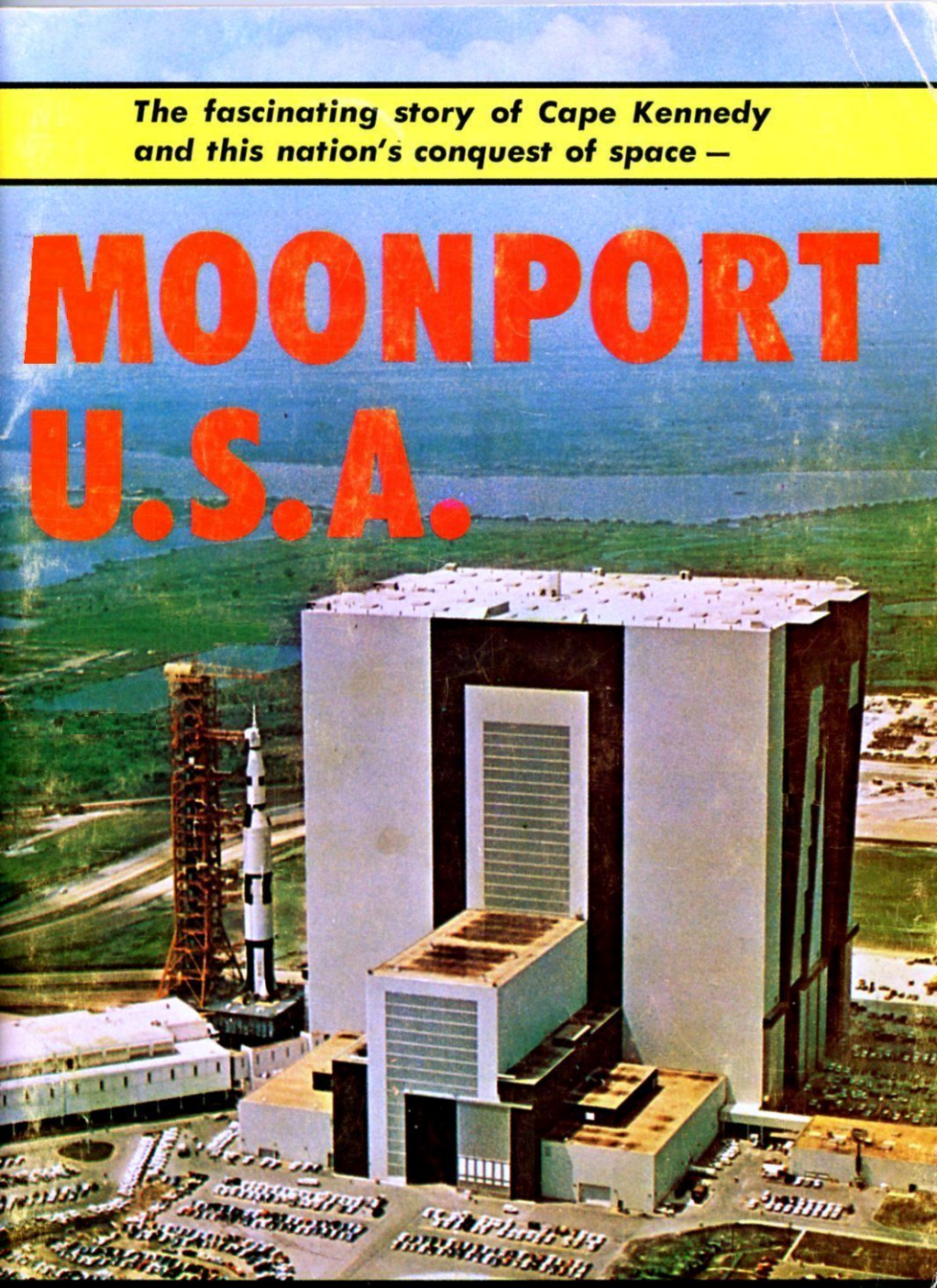
The fascinating story of Cape Kennedy and this nation's conquest of space —

MOONPORT U.S.A.



An Authoritative Illustrated Handbook on Technology, History and Future of Space

Cover:

America's biggest rocket, the Apollo/ Saturn 5, trundles out of the world's largest-volume building—the Vehicle Assembly Building — at the Kennedy Space Center in May, 1966.

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Moonport, U.S.A.

by

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and Edited by the

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FOREWORD

For a better public understanding of our nation's missile and space programs and the new technology supporting them, the Air Force Eastern Test Range Public Relations Association has commissioned this book to be written.

The Association members listed below played an active part in this book, contributing both data and photographs as well as checking and reviewing the copy for accuracy. They have stamped it "up-to-date, authentic and complete."

In layman's terms, this book explores the history and technology of our space programs and provides a glimpse into tomorrow. We think you will find the book stimulating, entertaining and educational.

The Editors

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Prelude to the future

What the U. S. space effort means to this country and the youth of today

Bottom to top: Virgil Grissom, Edward White and Roger Chaffee, America's first Astronauts to give their lives in a manned Apollo mission, perished during tests of NASA Apollo/Saturn 204 Earth Orbital Mission in January 1967.

The Beginnings

Man has always done better than he thought he would. He set out to find a new route between Europe and the Orient and instead stumbled on the riches of the New World. He set out to build a machine capable of self-propelled flight and later found he had made possible an industry which last year flew more than 70 million people to all parts of the world.

In the last several years, man has set out to learn if he can live and work in space — and no one knows for certain where this latest venture will lead. It might end in the colonization of new planets presently unknown to man, or it might lead to the discovery of other forms of life in this universe — perhaps of equal or greater intelligence than his own.

The end result of nearly all man's explorations has proved to be something which could hardly have been imagined at the outset. Try to visualize Christopher Columbus justifying the cost of his expedition before Queen Isabella by describing to her the factories, wheat fields, ball parks, skyscrapers, medical laboratories, air-conditioned homes and more than 200 million people which someday would exist on the land he sought to discover. He never would have made the trip.

The situation today at the beginning of the Space Age is comparable. Man knows that he can survive in the harsh environment of space and that he can

rform useful work there — weather servations and scientific experimentaon are only two examples. But where ll it all lead?

The history of man suggests that if an knew the answer to this question, would not bother with it. It has been e mystery of the unknown which has imulated man to make full use of his telligence and many skills. It is impssible today to say what man's present forts in space will lead to, but if the ast is any indication of the future, the enefits will be many and varied.

Benefits

Toward those unknown benefits, the .S. space program has been developing a rapid rate; it now is one of the top dustries in the nation and continues to ove higher every year. Some predict that ithin the next 20 years, the space industry will employ more U.S. workers and emand the specialized services of more ms than any other, steel and automove included.

Today, thousands of firms and several ndred thousand people are engaged in l the various U.S. space programs, both vilian and military.

Is this effort, this great expenditure of lent and money to conquer space, really orth it? The late President John F. ennedy once said that the exploration of pace would happen, whether or not the nited States cared. But he noted that is nation had always been among the rst to greet a new age, such as the industial revolution or the nuclear era, and he lt that America should be "the world's ading space-faring nation." He urged e country to "set sail on this new sea."

"But why, some say, the moon?" he id in a 1962 speech. "And, they may ell ask, why climb the highest mountin? Why, thirty-five years ago, fly the tlantic? We choose to go to the moon in is decade and do the other things not ecause they are easy, but because they re hard; because that goal will serve to rganize and measure the best of our enrgies and skills. Many years ago, the reat British explorer, George Mallory, ho was to die on Mount Everest, was sked why did he want to climb it, and he id: 'Because it is there.'

"Well, space is there," President Kenedy continued, "and the moon and lanets are there, and new hopes for nowledge and peace are there."

It is a truism that great rewards involve reat risks and sacrifices. This hard fact was brought painfully home to the nation and the world on the evening of January 27, 1967, when astronauts Virgil I. ("Gus") Grissom, Edward H. White, 2nd, and Roger B. Chaffee died inside the blazing inferno of their Apollo spacecraft.

Grissom had contemplated the threat of death earlier in his astronaut career. He looked at it objectively: "If we die, we want people to accept it. We are in a risky business and we hope that if anything happens to us, it will not delay the program. The conquest of space is worth the risk of life."

Educational Requirements

This exacting requirement places heavy responsibilities on the men and women who are assigned to these tasks of planning, designing, building and using space equipment, or "hardware." Specifically, it means that they must be well-educated before they can even apply for these positions and that they must be prepared to continue the learning process for the rest of their working years. Even the production-line worker must be better trained than ever before.

Many colleges and universities throughout the United States have recognized the importance of space by establishing departments of space technology or space science. There, students can begin to acquire some knowledge of the chemistry, physics, mathematics and electronics required for a career as a space engineer or scientist.

But the student who wishes to go far in a space career, must do more than win his bachelor's degree. Personnel recruiters today are not surprised to see MS or PhD degrees on an applicant's record; this level of education is needed in some areas — just to start.

The rewards of a career in space, however, are ample. The salaries being paid today are handsome, both in government and in industry. But many who are in the business today consider the intellectual rewards — of discovering new facets about our universe and its origins — to be worth more than dollars.

This book is a comprehensive account of the many U.S. space programs which have originated at Cape Kennedy, Fla., and traces their development down to the present time. It also sketches the future plans of the U.S. to explore further the depths of space and describes — in layman's terms — some of the fundamentals of science which make space exploration possible.

Triangularly-shaped Cape Kennedy, America's spaceport, juts out into the Atlantic Ocean in this aerial photograph. Many space engineers live in nearby Cocoa Beach (foreground).

Cape Kennedy

The Testing Grounds of Space and *Moonport*, U.S.A.

Cape Kennedy, as a place, is to space what Kitty Hawk, a small North Carolina village, is to aviation.

Although not the first site from which a U.S. rocket was fired — Dr. Robert H. Goddard, America's rocket pioneer, launched a number of small vehicles at Roswell, New Mexico, in the mid-1920s and U.S. Army scientists fired captured German V-2 rockets at White Sands, also New Mexico, right after World War II, Cape Kennedy (or Canaveral, as it formerly was named) has been the site for the United States' first space efforts and from which it soon will head for the moon.

"The Cape," as it is called by most missile engineers and people whose work is associated in one way or another with this missile-launching government reservation, is a triangular-shaped piece of land jutting out into the Atlantic Ocean. It covers roughly 15,000 acres and, to the surprise of many people visiting it for the first time, is a peninsula among the many hundreds of islands which splinter the east coast of the Florida peninsula. It is approximately 10 miles offshore from the Florida mainland.

The Kitty Hawk of Space

The oldest map known to show the Cape as a distinct, recognizable geographical feature is a Spanish mariner's chart of about 1550. Spanish sailors, moving up and down the coastline of this then-newly discovered continent, named it "Canaveral" (Spanish for "cane" or "canebrake") because of the abundant thickets of the brittle, hollow reeds that grew there.

Indians apparently knew the Cape and made use of it, for archeologists have found arrowheads, bones, ornaments and pottery scraps beneath the Cape's sands.

Because the Cape posed a navigational hazard to ships during fog and darkness, the federal government in 1847 established a lighthouse on its tip.

The only other use made of it was

some farming and fruit-growing.

5,000-Mile Shooting Gallery

The Cape began to change character in 1947 when a Department of Defense team, looking for a site from which America's then-new long-range guided missiles could be launched, investigated its possibilities. It had many advantages.

The area was sparsely populated and, standing at the tip of the Cape, one could look down into the South Atlantic Ocean and see a 5,000 mile-plus shooting gallery of open water. Finally, there were many Caribbean islands standing just off to one side of this 5,000 mile strip, where radars and other electronic instrumentation could be set up to monitor the flights of these research and development missiles.

On May 11, 1949, Pres. Harry S. Truman signed a bill which established the construction of a missile range, then called the Long Range Proving Ground, with its first and central station to be located at Cape Canaveral. Slightly more than a year later, the Department of Defense assigned the responsibility for the Range to USAF.

During the first several years of operating the Range, the Air Force discovered that it would be better to do the job with an industrial contractor rather than with military personnel. USAF picked Pan American World Airways and the Radio Corporation of America (RCA) in 1953 to assist in the operation of the Range.

This government-industry partnership set a pattern for other federal agencies, such as the National Aeronautics and Space Administration, when it established its own organization and facilities on the Cape and adjacent Merritt Island between 1960 and 1963.

NASA, the civilian space agency, selected Trans World Airlines (TWA) in 1963 to be the base manager of the sprawling complex built on Merritt Island for the man on the moon program. Although it might at first seem strange to find a division of a commercial airline active in a spaceport, the fact is that TWA — like Pan American — has excellent credentials for the job. TWA's experience with its own maintenance and overhaul base in Kansas City, Mo., where it maintains its large fleet of jetliners in top condition, enabled the airline to step into the John F. Kennedy Space Center and operate similar metal, machine, electrical and other shops to support space vehicles. TWA also looks after the roads and grounds of the Kennedy Space Center,

A lighthouse and Coast Guard station stand on the tip of the Cape.

electrical utilities, supply services, fire and security protection, medical care and janitorial services.

NASA also uses the services of The Bendix Corporation, Ling-Temco-Vought, Inc., RCA, Federal Electric Corp. (a subsidiary of International Telephone & Telegraph), and others to provide specialized services in running this spaceport. Each company and each employe does his share to make every launch successful.

First Missile

The first missile flown from the Cape was a two-stage Bumper, consisting of a captured German V-2 as the first stage and an Army WAC-Corporal rocket as the second stage; the date was July 24, 1950. The size and simplicity of that first launch pad stands in sharp contrast

Excellent narrated tours of the John F. Kennedy Space Center and Cape Kennedy are now provided by TWA for NASA daily. Well informed guides help make this a highly educational, exciting look at our space programs.

with the facilities needed for the Uprated Saturn I vehicle today.

In the years since, the Air Force, Army, Navy and NASA have launched in the neighborhood of 1,500 missiles and satellite-carrying launch vehicles. Obviously, not all have been successful. But the overall percentage of successes — estimated at about 80% today and inching higher every year.

World's Largest Laboratory

The Range is more than just a clear field down which rocket vehicles are flown. It has been called the "world's largest outdoor laboratory" and it is. But that describes only part of its job. The Range also guides satellite-carrying launch vehicles into orbit and provides ground tracking stations for some satellite missions — such as Project Mercury.

Physically, the Air Force Eastern Test Range takes the form of one central facility—the Cape Kennedy Air Force Station (formerly called the Cape Canaveral Missile Test Annex of the Air Force Missile Test Center), where all activity originates — and a series of 13 tracking stations in the North and South Atlantic Oceans, augmented by a fleet of ocean-going tracking ships and specially-instrumented aircraft.

In addition, the Range can be — and usually is — tied in on the same communications link with the other U.S. tracking nets.

A typical tracking station, located on a small Caribbean island, would be staffed by anywhere from eight to several hundred men, and equipped with a pulse-type tracking radar, two or three different telescopic cameras, at least one and possibly two telemetry antennas, and several communications transmitters and receivers.

If trouble should develop with one of these items — such as the radar — the day before a launch and cannot be repaired in time to cover the missile's flight, the flight might be, and frequently is, postponed until the station is back in operation once more.

Such is the importance of these stations to the success of any individual missile or a total program.

Missile Tracking

Tracking a missile as it flies downrange serves two major purposes:

- **Safety.** Because of the great damage a 100-ton rocket vehicle could do if it wandered off-course and fell on populated areas, it is watched very closely to make certain that it sticks to the path planned.

If it begins to wander from this path, the tracking stations can tell within 5 ft. when a deviation has occurred and corrective signals can be sent to the vehicle's guidance system to bring it back.

If the errant missile should fail to obey these commands — and this has happened on more than one occasion — the Range Safety Officer can send a signal to an explosive charge on the missile; the charge detonates and rips the missile apart while it is still over water.

- **Information.** Since the purpose of

The late Pres. John F. Kennedy, for whom the Cape was re-named after his assassination in 1963, visited the Cape several times to be briefed on the nation's space programs.

A technician at a down-range tracking station makes notes before racks of telemetry equipment.

any flight is the acquisition of knowledge, the down-range stations (as well as the Cape) are equipped to gather as much information as the vehicle can send and either store it for later shipment by aircraft or ship, or transmit it by cable or radio back to the Cape.

Some of this information is needed immediately — such as engine performance or an astronaut's physical status — and so is relayed back as rapidly as possible.

Other data — such as the temperatures on the skin of the vehicle — can be put on magnetic or paper-punch tape for safe-keeping and studied later, after the flight is over.

Pre-Launch Preparations

The Pan Am and RCA engineers who man these stations usually begin working on a launch about two days before the missile is to be fired from Cape Kennedy. They receive classified documents from the Air Force Missile Test Center, the clearing house through which all agencies desiring to use the Range must pass.

These documents outline the objectives of the up-coming launch, describe the pre-planned trajectory which the missile hopefully will fly, spell out what tracking equipment at the station will be used and how it will be used (what angles the radars should be set at, what time the cameras should be turned on, how long they should run, etc.).

The station engineers then match these requirements against the station's equipment (1) to see if all the called-for radars and cameras are in good working order and (2) if the equipment can perform the tasks set for it by the Air Force center back up-range.

The remainder of the time until the day of launch is spent in preparing the equipment, testing and calibrating it, and performing whatever maintenance is necessary to insure the system's working condition.

Locking On

On the day of launch, the engineers listen to the countdown on a special radio frequency used only by the Range. They know how long it should take for the missile to reach their station after it has been launched. After the missile has lifted off from Cape Kennedy, they know that they should electronically see it — after, say, nine minutes and 20 seconds of flight.

When this time comes, they watch their dials and oscilloscopes to determine if the tracking systems have located the missile and are "locked" on it.

Even if the missile is not exactly on the predicted flight-path, it still can be tracked. All launch vehicles must carry a special transmitter which transmits a constant tone signal. The telemetry antennas, being small and having wide reception angles, can be swept back and forth through the sky until they detect the signal.

Then, through electronic links between the two, the tracking radar can be told exactly where to find the missile. Once the larger systems have a lock on it, the vehicle either can be commanded to return to its proper path or it can be destroyed.

Assuming that everything is normal, the station would continue to track the

speeding missile and send data back to the Cape where the computers determine whether everything is as it should be.

The station would store this tracking data on special tape recorders as insurance against a break in the underwater cable leading back to the Cape or garbles in radio transmissions. All the telemetry data poured out by the vehicle as it passed overhead also would be tape-recorded.

These tapes then would be shipped back to the Cape within a day or so after the flight and "reduced" on computers, or made meaningful.

Life On The Range

When a missile is not flying, these engineers spend their working days repairing their systems or making the modifications to improve the performance of the tracking systems.

They also spend a large percentage of their time studying proposed new systems — such as a laser tracker — to see how it would fit into the station, and making their suggestions.

Life on these tracking stations, like anything else, has its advantages and disadvantages. Some are so remotely located in the ocean and are so small that the men who man them cannot bring their families with them. So, they are paid a handsome bonus if they will serve 12 to 18 months on the station.

Ships and aircraft come into the island regularly, bringing with them supplies of food, mail, books, movies, spare parts, training manuals, or any one of a thousand items which might have been ordered.

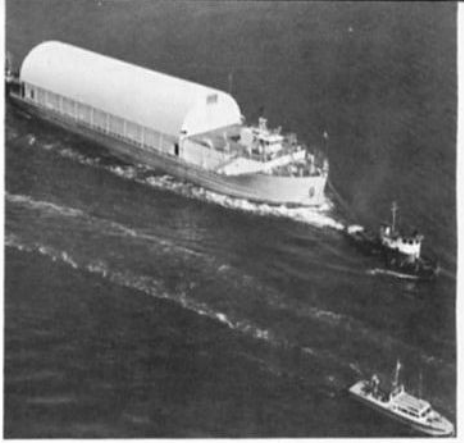
Other stations, such as the one on Antigua, are large enough so that some of the engineers assigned there can bring their families with them. The Antigua site, in fact, is considered a "plum" among the downrange stations.

Impact of the Moon Decision

The Cape and the Range began to feel the impact of the late Pres. Kennedy's man-on-the-moon decision within months after it had been made in May, 1961.

In August of that year, NASA, with Congressional approval purchased 80,000 acres (an additional 8,000 was included later) of land behind and north of the Defense Dept. reservation of Cape Canaveral.

The bulk of this new land lies on Merritt Island, a giant tract between the peninsula — on which the Cape is located — and the Florida mainland.



The barge, "Promise," is used to haul Saturn boosters to Florida from Alabama.

It is a huge piece of land, but huge launch vehicles and spacecraft demand huge facilities: NASA's Vehicle Assembly Building, where the three stages of the Saturn V launch vehicle are assembled to make a complete vehicle, stands 52 stories tall, covers eight acres and encloses a volume of 125 million cubic feet.

The building is divided into two sections — a "high" and a "low" bay area. The low area is 20 stories tall and consists of eight garage-like bays where the second and third upper-stages are delivered, inspected and prepared. From there, they are moved by overhead cranes into the 52-story section.

Within the World's Largest Building

NASA engineers have come up with a clever method of assembling and launching a vehicle as large (360-ft.) and heavy (500,000 lb.) as the combined Apollo/Saturn V vehicle: they do all their work on a large movable platform called a Mobile Launcher, which they move from place to place.

During the assembly process, the launcher is positioned in one of the four high-bays and provides a table top 160-ft. long, 135-ft. wide and 25-ft. thick on which the Saturn V may rest.

The three stages are lifted, one at a time, and assembled on top of each other to make a Saturn V, and then the guidance segment and 55-ft. long Apollo spacecraft are added. Umbilical arms and personnel cat-walks run to the various stages from the 380-ft. tall tower. They are an integral part of the launcher, and provide electrical power, air conditioning, and purging gases to sustain

The world's largest airplane, "The Pregnant Guppy," flies smaller Saturn stages from California to the Cape. One is visible (left) as the plane is opened.

the vehicle in its "ready" status.

When finally ready for launch, a diesel-driven tractor-like vehicle drives in beneath the Mobile Launcher—and the empty Apollo/Saturn V—and picks it up on four enormously powerful hydraulic jacks and the 3½-mi. drive to the launch stand begins — at 1 mph.

The stand basically is only a pedestal to which the launcher is anchored. Once it is in place, the transporter backs out and returns to the assembly area, and within a week or so, the Apollo/Saturn V is launched.

The virtue of this approach is that it does not tie up the stand for long periods of time. In comparison, some early Saturn vehicles were assembled on the same stand from which they later were launched, the entire process taking several months and during which time no other vehicle could use that stand.

A Complete City

A few miles to the south of this assembly area is an industrial park where the Kennedy Space Center makes its headquarters.

Here a small city, including office buildings, a spacecraft operations and checkout hangar, a bank, hospital, post office, telephone exchange, cafeterias, warehouses, railroad yard, sewage disposal plant and power station copes with the needs of our first moon port.

The Air Force's Titan III space launch vehicle has also adopted the vertical assembly concept.

Man-made Islands

Since land on the Cape is scarce, the Air Force has created a series of man-made islands in the Banana River which flows between the Cape and Merritt Island. On one of these islands is USAF's equivalent of the civilian space agency's Vehicle Assembly Building, a 20-story-tall Vertical Integration Building.

This structure consists of four high bays in which an equal number of Titan III's can be assembled. Only the core of the launch vehicle — the three-stage Titan II—and the payload are assembled together in this facility, on a rail-mounted platform comparable to the Saturn V's Mobile Launcher.

All the electronic equipment used to check out and support the core and the payload is housed in a series of railroad boxcars, coupled to the base of the platform.

After checkout, diesel locomotives pull the platform and its core-payload passenger to another island, where the solid motor assembly building sits.

Here the five-segment, 75-ft. tall solid-propellant motors which are the vehicle's first stage are put together. The diesels move the core and the un-manned vehicle alongside loading platforms within the building and the solid motors are "strapped on" to the side of the core.

The diesels then continue the trip out to the launch stand, where the electronics boxcars are inserted in blast-proof shelters and the platform tied down. The core of the launch vehicle then is fueled and the vehicle is ready for launch.

Original Launch Areas

The emphasis on the Cape reservation now lies at the north end of the 15,000

A test version of the capsule and rocket combination that someday will carry three U.S. astronauts to the moon was carried slowly out of the space agency's Vehicle Assembly Building — similar to an aircraft's hangar — in May, 1966.

acre original reservation, where the Uprated Saturn I and Titan II stands are located.

The old IRBM stands on the south face of the triangular Cape now sit quietly for months at a stretch between Delta launches; that is the only vehicle which flies from that section of the Cape.

ICBMs no longer thunder into the skies from ICBM Row, as the north slope of Cape Kennedy is known. Of four Atlas and four Titan stands, only two were still in service after 1966 and those two Atlas-Agena pads, used by NASA to loft satellites into orbit, were scheduled to be discontinued by 1969.

Two other Atlas pads were built specifically for the Atlas-Centaur combination. Designated Complex 36A and 36B, this pad — and the Atlas-Centaur — are expected to be used by NASA through the early 1970s to loft satellites weighing up to 000 pounds into earth orbit.

The four Titan stands, one of which was the springboard for 10 two-man Gemini flights, have all been mothballed or dismantled.

In the late 1950s and early 1960s, there were some 20 active pads on the Cape and the yearly number of launches usually ran well over 100. Today, there are about one dozen active stands — half of which have been built in the last few years — and the number of yearly launches has dropped to 20 to 40.

This decrease does not reflect a deduction in the nation's determination to master space. Rather, it indicates that the nation has achieved a reliable ballistic missile force capable of defending the United States against any enemy's attack, and has shifted its emphasis now to the long-term task of mining the rich seams to be found in space.

The first missile launched at Cape Kennedy—Bumper 1-8, July 24, 1951.

Probing space

The major missile and satellite programs from Cape Kennedy

Sooner or later, practically every U.S. probe, launch vehicle and satellite comes to Cape Kennedy for flight.

If missile or launch vehicle, it comes to prove itself in a series of research and development flights. If satellite or probe, it comes to be launched into orbit.

With the exception of a few short-range Army and Navy missiles, every U.S. missile and launch vehicle has made at least one flight from Cape Kennedy. More than a third of all U.S. satellite programs have had their point of origin at the Cape. A few, mainly secret military programs, use the Pacific Missile Range.

Research and Development

A research and development program is a series of tests similar to those which new aircraft and automobiles are subjected to and are meant to determine if the vehicle performs as well as its designers claim it will.

Winged Missiles

The earliest research-and-development vehicles flown on the Atlantic range were winged missiles, the Martin Co.'s 650-mi. range Matador and the 5,000-mi. Snark, both of which basically were pilotless bombers.

Although not the first vehicle to be flown on the Range—the Bumper holds that distinction—the Matador was the Air Force's first missile program to be flight-tested and also was the first such program to be completed.

All told, 154 Matadors were flown on research-and-development (R&D) flights between the first on June 20, 1951, and the last, on Nov. 30, 1956. In addition, 132 Matadors were flown as training vehicles by the Air Force crews who later stood guard in Europe with two squadrons of the weapon.

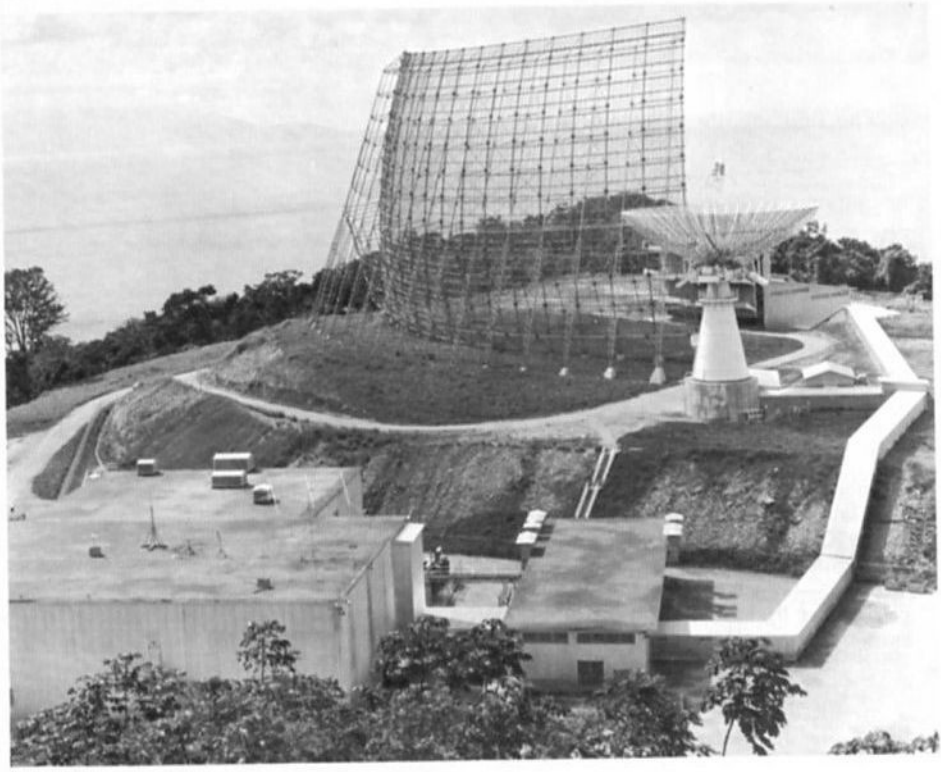
Snark, the first long-range U.S. missile, made 97 flights down the Range between Aug. 29, 1952, date of its first flight, and Dec. 5, 1960, date of its last vehicle.

Other Air Force pilotless winged missile systems included the Navaho, a two-stage vehicle based on a German World War II concept of a skip-glide bomber, which made 26 flights between Aug. 19, 1955, and Jan. 29, 1959, when the program was terminated (it never became an operational weapon); and the Martin Co. Mace, an improved and longer-range version of the Matador. The Mace made 44 R&D flights between Oct. 29, 1959, and July 17, 1963, and still is occasionally flown by Air Force crews in training.

Early Ballistic Missiles

But the days of these cruise missiles, which flew like conventional aircraft, were numbered by the advent of the ballistic missile, which flies like an artillery shell in a long arc from launch stand to target in minutes.

The Trinidad station on the Atlantic Missile Range uses these two large, experimental radars to track missiles flying down-range.



A tense moment in the blockhouse—the end of the countdown is near and the missile will be launched any second now. Each man is monitoring some critical function of the missile through the dials and meters on the panels before him.

The Army's 200-mi. range Redstone, built by the Chrysler Corp., signaled the end of the winged missiles when it first flew on Aug. 20, 1953. It made 18 R&D flights, was used as a booster for other programs in nine launches and served the Mercury manned space flight program six times—two of those six being the vehicles which lifted astronauts Alan B. Shepard and the late Virgil I. Grissom briefly into space.

Thor

It was the mid-1950s when the U.S. began to fly its long-range ballistic missiles.

The Douglas Aircraft Co. Thor, a 65-ft. tall, 110,000-lb. (fully-fueled) ballistic missile with a range of 1,700 mi., made its first flight on Jan. 25, 1957—just 13 months after Douglas received the contract from the Air Force. Its debut, like so many missiles in those pioneering days, was less than perfect: a tank ruptured and the IRBM (intermediate range ballistic missile) exploded in a tremendous fireball.

It was not until the fifth vehicle that Thor scored a completely successful flight and then, powered by a single Rocketdyne engine of 135,000 lb. thrust (later increased to 150,000 lb.), went on to score a creditable record during 49 R&D launches on the Range.

Thor stood guard in England for several years, until the Atlas and Titan ICBMs were ready to assume the defense of the U.S., and then returned to America. Those Thors have since been converted into space boosters and are continuing to uphold the vehicle's good reputation as a reliable space launch vehicle of more than six-years standing.

The Army's Jupiter, also built by Chrysler, was a contemporary of Thor and, although developed by the Army, was assigned to Air Force units for operational deployment. The 58-ft. tall, 110,000-lb. missile (shorter but wider than Thor) made a total of 65 R&D, crew training and space launches between May 31, 1957, and Apr. 27, 1961, and its record also was above average.

Five months after the first Thor and two weeks after the first Jupiter, the Air Force launched its first ICBM (intercontinental ballistic missile)—the General Dynamics Atlas—on June 11, 1957.

Atlas

Atlas was then, and is today, a "one-of-a-kind" rocket vehicle: its airframe is held up not by an internal skeletal structure, but by high-pressure gas. And although it has a one-piece airframe, it is classified as a stage-and-a-half missile because it discards two of its three Rocketdyne engines—called the "boosters"—after about 2 min. of flight and then continues on with the thrust of a single "sustainer" engine.

Atlas stands about 83 ft. tall, has a 10-ft. diameter and weighs about 255,000 lb. when fully-fueled; its booster engines are rated at 165,000 lb. thrust each and the sustainer at 59,000 lb.

Map shows the extent of the Air Force Eastern Test Range, from Florida to the Indian Ocean.

The Air Force used two different types of Atlas for several years at bases throughout the United States. The D-series Atlas, first to become operational, used a radio-type guidance system. The E-series and F-series Atlas used all-inertial guidance systems; the former were stored in coffin-like structures above the ground while the latter were placed in underground silos. Atlas retired from active duty as a military weapon in 1965.

Failures Corrected

Atlas' first flight ended the same way the first Thor's did: in a deafening explosion. When the second Atlas exploded in an almost identical fashion slightly more than three months later, it illustrated the basic reason for a research-and-development program—learning.

Analysis of both failures led the Air Force to the discovery that part of the exhaust gases from the engines was flowing back into the engine compartment and melting electrical cabling and plumbing lines routed there. The missile literally was burning itself up.

The solution, eventually adopted by most U.S. multi-engine vehicles, consisted of the addition of a heat-shield just above the engines to deflect the gas flow away from the base of the missile.

Despite a slow start, Atlas—like Thor—eventually got rolling. It too chalked up a commendable score for itself during the course of an 85-vehicle flight test program which ended more than five years later on Dec. 5, 1962.

In that time, Atlas scored a number of firsts, among which: it was the first U.S. missile to reach full ICBM range of 5,000 mi. (Nov. 28, 1958) and the first to fly more than 9,000 mi. into the Indian Ocean (a feat repeated twice after that first such flight May 20, 1960, on Sept. 19, 1960, and again on July 6, 1961).

Atlas also flew itself into orbit Dec. 18, 1958, carrying a tape-recorded Christmas message to the world from then Pres. Dwight D. Eisenhower and, on the missile flown Aug. 24, 1959, returned the first films ever taken of the earth from an altitude of 700 mi.

Atlas stayed on, after its missile R&D phase was finished, to serve as a booster for a wide variety of missions.

Titan I

Titan I was the Air Force's second ICBM project and was developed as insurance against the possibility that Atlas might be late in development.

Built by the Martin Co., the Titan I was a two-stage 90-ft. tall, 10-ft. diameter missile which weighed more than 220,000 lb. and which carried a nose cone nearly twice as heavy as that on the Atlas.

First flown on Feb. 6, 1959, the Titan I encountered some development problems as did all missiles, but at the end of a 47-vehicle test program, achieved one of the better success records of U.S. missiles. The Titan I is powered by two Aerojet-General Corp. first-stage engines of 150,000-lb. thrust each, and a single second-stage engine of 80,000-lb. thrust. It uses Bell Telephone Laboratories radio-command guidance.

Polaris—protecting America from beneath the surface. ▶

Thor IRBMs, once stationed in England, lie in an Air Force hangar in Okla. where they are overhauled and converted to space-booster work.

Titan II

In June of 1960, as these other ICBM programs were well underway, the Air Force announced its decision to develop a second and totally different Titan missile system—to be called Titan II.

It is taller, at 102 ft., and heavier, at nearly 300,000 lb., than any previous ICBM. It also uses liquid fuels which are stored at approximately ambient temperatures and which ignite spontaneously upon contact with each other.

Guided by an AC Electronics all-inertial system and powered by Aerojet engines delivering a total thrust of 530,000 lb. (two 215,000-lb. thrust engines in the first stage; a single 100,000-lb. thrust engine in the second stage), the Titan II is designed to be fired directly from the bottom of its underground silo and can hurl the heaviest nose cone in the U.S. stockpile—the General Electric Mark 6—farther than any other missile.

Titan II, with its startling transparent exhaust, was first launched Mar. 16, 1962. Although the missile had some second-stage difficulties early in the program and had a natural vibration called the "Pogo-stick effect" which had to be eliminated before NASA would use the vehicle to launch manned Gemini capsules, Titan II had only one total failure in 23 launches. No other ICBM has had so few vehicles in its flight-test program or so few total failures.

Minuteman

After several years of guarding the nation from its mineshaft-like tubes buried deep in the ground, the Titan II was ordered by the Defense Department in 1967 to phase out by the end of the decade. The Titan I had been taken out of the active missile inventory at about the same time as the Atlas.

The missile that today shoulders a very large part of the nation's defense is the Air Force's Minuteman ICBM. The three-stage missile, which has been continually improved in successive models (Minuteman-1, Minuteman-2, and Minuteman-3) uses a rubber-like solid propellant. It is this propellant which permits the missile to be stored in underground silos for long periods of time and yet be fired in a second; it is this long-storage, quick-reaction characteristic that led to the decision to replace the Atlas, Titan I and Titan II missile with Minuteman-2 and -3 forces.

The 53- to 59-ft. tall missile (height varies between early and later models) weighs about 80,000-lb. and, guided by an Autonetics (a division of North American Aviation) all-inertial system, can place a small warhead on targets more than 5,500 miles away.

One of Minuteman's principal advantages is that it can be stored in underground silos for long periods of time and still be fired at a moment's notice. The weapon made its first flight-test on Feb. 1, 1961, and although two early models have completed their test programs, the missile still is in a research-and-development phase.

Polaris

The Navy's Polaris fleet ballistic missile began life back in 1955 as a seagoing version of the Army's Jupiter

IRBM; it was to be carried in the holds of surface vessels.

Because of the complexities of handling large quantities of liquid propellants on a rolling sea, the Navy never was too enthusiastic for the idea and finally, in December, 1956, received permission to (1) develop a small solid-propellant missile and (2) take it below the waves in a submarine.

To be accurate, the designation "Polaris" includes more than the missile itself; it includes the nuclear submarine which launches the two-stage weapon.

There are three models of the Lockheed-built fleet ballistic missile, the A-1, A-2 and A-3. Still a fourth model, called Poseidon, is in the early stages of development.

The A-1, first of the Polaris family, is about 28-ft. tall and weighs about 30,000 lb.; it has a range of 1,400 mi. The A-2 resembles the A-1 in general appearance, but its first stage is longer by about 30 in., and its fuel is a more powerful propellant. With a range of 1,800 mi., the A-2 has replaced the A-1 on all submarines originally equipped with the earlier weapon.

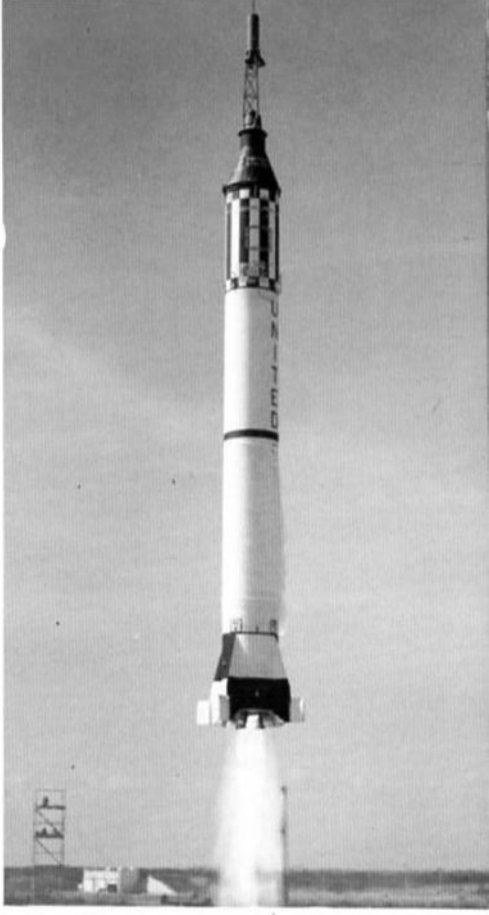
The A-3 is about the same length as the A-2, but has a constant diameter of 54 in. in both stages (the A-1 and A-2 have a Coke-bottle shape), more powerful propellants and glass-fiber motor cases instead of steel. Added up, all this gives the A-3 a range of almost 2,900 mi.

To date, there have been over 200 Polaris A-1, A-2 and A-3 launches down the Eastern Test Range. Roughly half of these missiles have been flown from land pads on the Cape; These were research-and-development vehicles. The other half were fired from submarines lying beneath the waves 20 to 30 miles offshore from the Cape; these were training shots for the submarine crews.

The first Polaris A-1 was fired from a land pad Jan. 17, 1958, and from a submarine July 20, 1960. All A-1 and A-2 missiles eventually will be replaced aboard the nation's 41 Polaris subs with A-3 and Poseidon missiles, whose longer range and heavier warheads make them more potent weapons.

Pershing

The Army and the Martin Co. joined forces on the 400-mi. range Pershing to produce one of the more outstanding programs ever seen on the Range: of 53 firings between Feb. 25, 1960 and Apr. 24, 1963, only two were rated as total failures and only six experienced partial troubles.



The chimpanzee, Ham, rode this Mercury capsule atop a Redstone booster in a successful prelude to manned flight in early 1961.

The two-stage, solid-propellant missile stands 34-ft. tall, weighs about 10,000 lb. and can be transported by helicopter. It rolls along the ground on a tracked vehicle, accompanied by three other tracked vehicles (communications, power-programmer, and warhead) and can be set up, ready to fire, in short time.

Defensive Missiles

The only defensive missile weapon system flown on the Eastern Test Range was the pilotless interceptor, Bomarc, which made 70 flights—including three against spare Navaho gliders—between 1958 and 1961.

There were other offensive systems: the air-launched winged missile, Hound Dog, which made 33 test-flights in more

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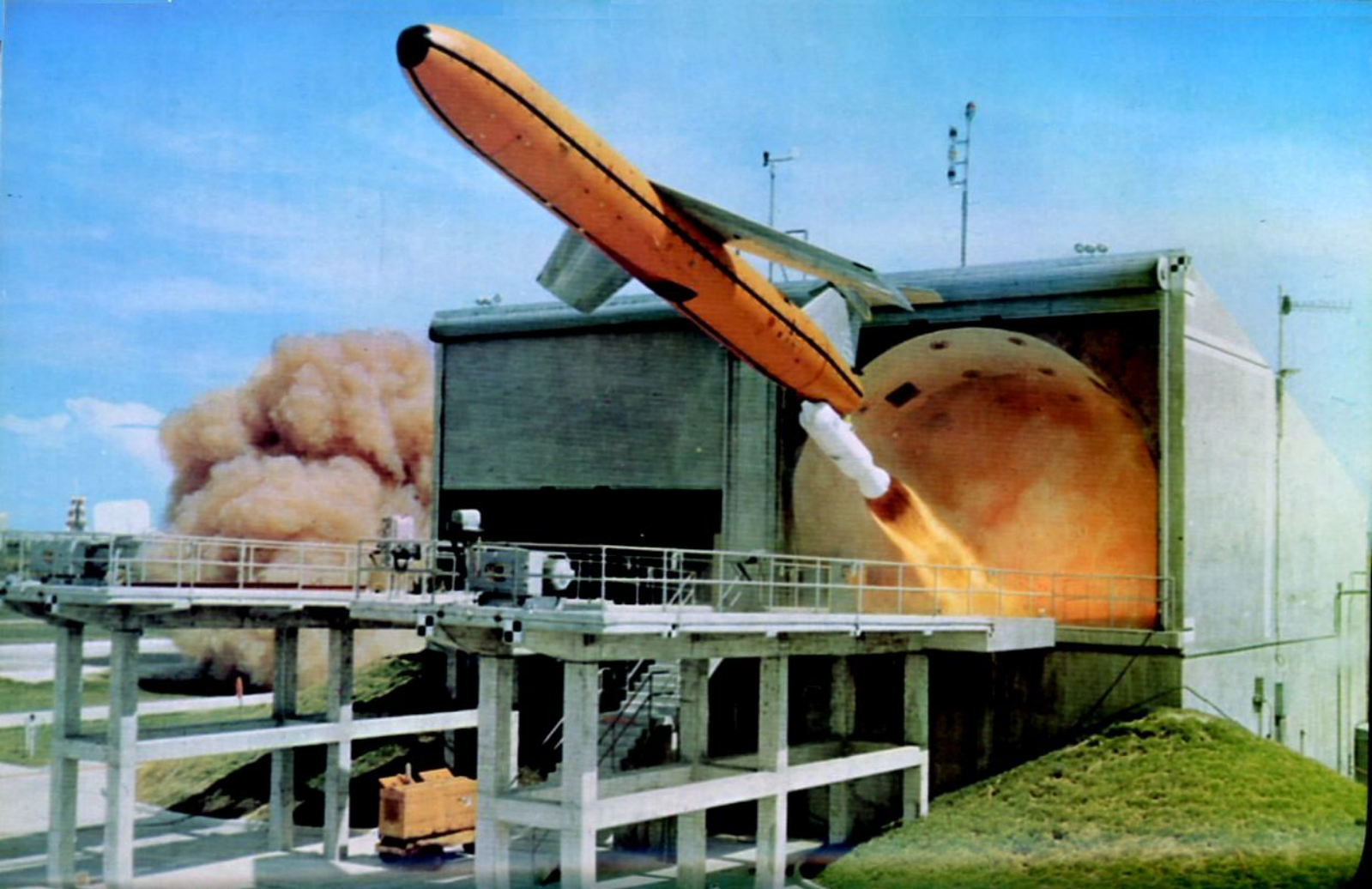
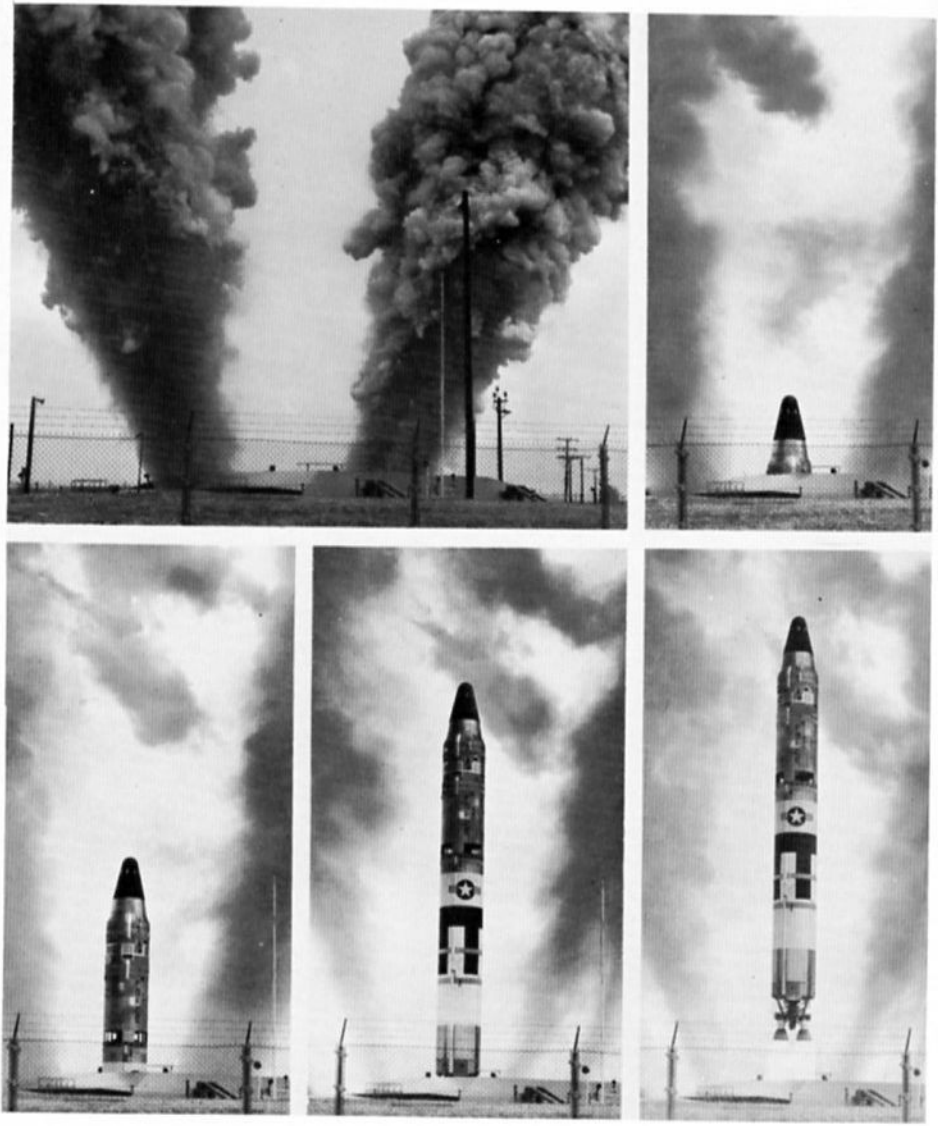




A Titan II, mightiest U.S. ICBM, roars out of its protective underground silo at Vandenberg AFB, Calif. In this sequence, the engine exhaust pours out of the W-shaped silo first, followed a second later by the missile's nose and, finally, the entire missile.

Atlas, the Air Force's first ICBM, lifts off its launch stand at Cape Kennedy. Note the ice which has condensed on the skin of the very cold liquid-oxygen tank.

Against a backdrop of ICBM gantries, a Titan II takes flight at the Cape.

than four years of development, and the air-launched ballistic missile, Skybolt, which made only six flights during its short and controversial lifetime.

Further Uses of Thor

A number of these vehicles in time became launch vehicle carriers for satellites. Thor, for example, has served as the first stage in:

- **Thor-Able,** a two-stage high-velocity inexpensive booster used by Air Force to test experimental nose cone materials intended for Atlas and Titan, and a three-stage vehicle used both by Air Force and NASA for an early series of mostly unsuccessful lunar satellites and deep-space probes. It is no longer used.
- **Thor-Able Star,** a two-stage vehicle used by the Navy for its Transit navigational satellite and by Air Force for the inter-agency ANNA (Army-Navy-NASA-Air Force) geodetic mapping satellite. It is not used any more.
- **Delta,** a three-stage vehicle used by NASA with considerable success in launching a variety of satellites, from 80-lb. Explorers to 500-lb. Solar Observatories; at one point, the Delta—with Thor as its first-stage anchor man—delivered 22 consecutive payloads into orbit before failing.

For some missions, the first-stage Thor of this composite vehicle is augmented by the thrust of three solid-propellant motors "strapped" to its sides.

Thor has been associated with more than 75 space missions on the Atlantic range.

Atlas Adaptations

Atlas, like Thor, has seen additional duty with a number of upper stages and satellites:

- **Atlas-Able** was a two-stage vehicle used by NASA and the Air Force in a series of three unsuccessful Pioneer probes and lunar satellites in 1959 and 1960. There are no plans to use this combination again.

- **Mercury-Atlas** was a slightly modified Atlas used, without any upper stages, to fly five un-manned Mercury spacecraft and then the Friendship 7 capsule of John Glenn (Feb. 20, 1962); the Aurora 7 craft of Scott Carpenter (May 24, 1962); the Sigma 7 spacecraft of Walter Schirra (Oct. 3, 1962); and the Faith 7 vehicle of Gordon Cooper (May 15, 1963).

- **Atlas-Agena** is a standardized two-stage launch vehicle, consisting of a D-series Atlas first-stage of 389,000-lb. thrust and a Lockheed Agena second-stage of 15,000-lb. thrust. It is used as a satellite booster both by Air Force (Vela Hotel) and NASA (Ranger, Mariner, Orbiting Astronomical Observatory, Gemini target vehicle, Lunar Orbiter and others).

More than 20 Atlas-Agenas have been flown on the Atlantic range, and more than 200 Agenas have been flown aboard Atlases and Thors at both Atlantic and Pacific ranges.

- **Atlas-Centaur** is another standardized two-stage vehicle, consisting of an Atlas and a Centaur second stage. The

An Air Force Minuteman ICBM, as seen from the top of its underground silo.

Centaur, powered by two 15,000-lb. thrust (each) engines, burns liquid hydrogen and liquid oxygen — the highest energy combination in use today in America.

Centaur, which can lift heavier satellites than an Atlas-Agena, had a rocky development. It fell badly behind schedule when it ran into a series of technical problems in the early 1960s. But these were eventually ironed out and the stage proved that it had come of age May 30, 1966, when it boosted the first operational Surveyor spacecraft on a very accurate trajectory toward the moon. To show that it was no fluke, it lofted the next several Surveyors just as precisely as the first to the moon.

In two separate flight tests during 1966, the Centaur tackled the problem of restarting hydrogen-oxygen engines in the weightlessness of space. The difficulty is in feeding the propellants in the right form, at the right temperature and at the correct pressure to the engines. But how would the propellants act in zero-gravity? Would the liquid oxygen and liquid hydrogen float away from the engine inlets so that when the engines were started, they would be sucking gas, rather than liquid, and the powerplants would consequently stall? The answer was to keep a small jet force on the stage so that the propellants were "packed down" on the engine inlets. How big should the jets be, however, and how should they be operated? Centaur's first crack at the problem was a disappointment when its little jets ran out of fuel too early. But the second flight was a resounding success and Centaur showed that a small peroxide jet was sufficient to keep the liquid propellants as calm as a mill-pond during the zero-gravity coast period between engine starts.

Saturn Launch Vehicles

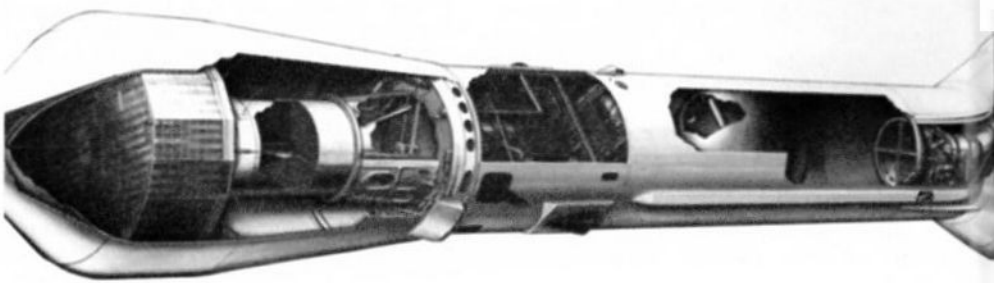
The Saturn family of large launch vehicles includes the two-stage Saturn I, the intermediate Uprated Saturn I and the advanced three-stage Saturn V. These launch vehicles are built up from the following stages:

- **S-1 first-stage** is a cluster of eight 70-in. diameter Redstone tanks (lengthened) wrapped around a central 105-in. diameter Jupiter tank (also stretched), the center tank and four of the peripheral holding liquid oxygen.

Propellants from these tanks, which are solidly joined together at the base by a thrust structure and at the top by a "spider-beam" assembly, feed eight Rocketdyne H-1 engines rated at 188,000-lb. thrust each. Total stage thrust is 1.5 million lb.

NASA's Marshall Space Flight Center at Huntsville, Ala., built eight S-1s and the Chrysler Corp., selected by Marshall

Cutaway drawing of the Delta launch vehicle shows tankage.



as the production contractor after the program had begun, built two. Ten of these vehicles have been flown flawlessly, and production of this particular design has ended.

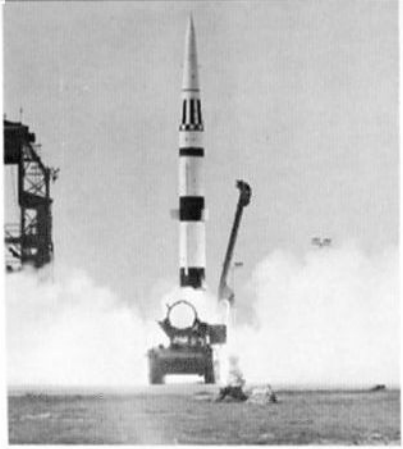
• **S-1B first-stage** is basically the same as the S-1, but has been redesigned to weigh almost 20,000-lb. less (down to about 90,000-lb. dry) and is powered by eight up-rated H-1 engines of 200,000-lb. thrust each, for a total stage thrust of 1.6 million lb. Re-configured fins at the base of the vehicle also are different from those on the last five S-1 stages. The Chrysler Corp. builds the S-1B at the NASA-owned Saturn manufacturing plant, New Orleans, La.

• **S-1C first stage** is the booster of the advanced Saturn V. It stands 138-ft. tall —roughly equivalent to a 14-story building—and has a diameter of 33-ft. It is powered by five Rocketdyne F-1 engines, each rated at 1.5 million lb. thrust, for a total stage thrust of 7.5 million lb. Boeing builds the S-1C at NASA's Michoud Plant in New Orleans, La.

• **S-2 upper stage** stands 82 ft. tall—the length of the Atlas—and also is 33 ft. in diameter. Built by North American, its five Rocketdyne J-2 engines (each rated at 200,000-lb. thrust) burn liquid hydrogen and liquid oxygen for a total stage thrust of 1 million lb.

• **S-4 upper stage** stands 42 ft. tall, has an 18½-ft. diameter and is powered by six RL-10 engines—the same as those on Centaur—for a stage thrust of 90,000-lb. Built by Douglas, it used liquid hydrogen and liquid oxygen. Only a few were built.

• **S-4B upper stage** stands 59 ft. tall, has a diameter of 22-ft. and is powered by a single 200,000-lb. thrust J-2 engine. It, too, is built by Douglas and was an outgrowth of the company's S-4 work.



An Army Pershing short-range missile leaps from its transporter-erector (foreground).

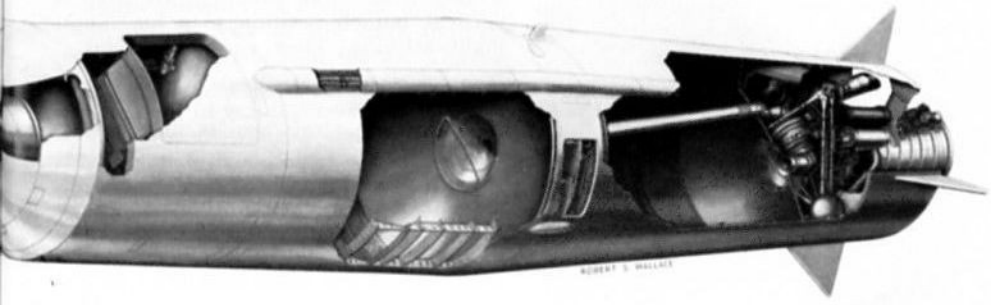
These stages are fitted together thus: the Saturn V consists of S-1C first-stage, S-2 second-stage and S-4B third-stage. The Uprated Saturn I consists of S-1B booster and S-4B second-stage—the same unit, with only minor modifications, as used as the third-stage on the Saturn V. The Saturn I consisted of S-1 first-stage and S-4 second-stage, but NASA decided to cancel this line after the 10 vehicles already manufactured had been flown.

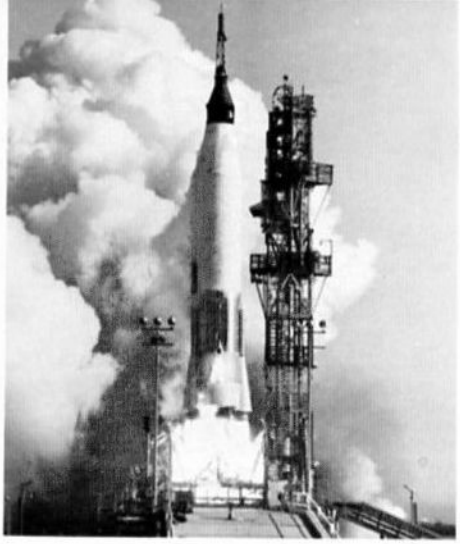
Titan III—MOL Booster

The Air Force's equivalent of the Uprated Saturn I is the Titan III space launch vehicle; it will be used to boost Air Force's Manned Orbital Laboratory plus a Gemini two-man spacecraft into orbit. A composite vehicle, the Titan III comes in two versions: the Titan IIIA and the Titan IIIC.

The Titan IIIA is a modified and more powerful Martin Co. Titan II, capped by a completely new upper stage

engine, plumbing lines and satellite payload.





A Mercury-Atlas vehicle lifts slowly off the launch stand.

—called the "transtage"—which has two Aerojet engines of 8,000-lb. thrust each. This vehicle is called the Titan III "core" and can lift almost 6,000 lb. to a low (100-200 mi.) earth orbit. Only four Titan IIIA vehicles were flown.

The Titan IIIC is capable of putting up 25,000 lb. into that same orbit. It consists of the core plus two 75-ft. long, 120-in. diameter solid-propellant motors strapped to the sides of the core's first stage. These motors generate more than 1 million lb. of thrust each.

At launch, only these solid motors are ignited and their thrust is sufficient to lift the entire vehicle to a fairly high altitude. At burn-out, these motors are jettisoned and the three stages of the core are successively ignited to drive the payload into orbit. The transtage, also built by Martin, can be shut down and re-started many times. Twelve IIIC vehicles now are on order

The Titan IIIC cannot lift as much payload into orbit as the Uprated Saturn I, which can boost about 40,000 lb. into low earth orbit.

Early Launch Vehicles

Earlier launch vehicles flown on the Range included the three-stage Vanguard (assembled by the Martin Co.), which was launched 12 times between Oct. 23, 1957, and Sept. 18, 1959, and orbited three satellites: Vanguards 1, 2 and 3.

There also was the now-concluded X-17, a small three-stage research rocket built by Lockheed for USAF to gather re-entry data applicable to other programs, and the Blue Scout, billed as a poor-man's research rocket (three- and four-stage versions), but which has seen more service in launches from NASA's Wallops Island, Va., Station and USAF's Vandenberg AFB, California.

Those launch vehicles adapted from Army missiles should not be forgotten.

There was the Jupiter-C, a modified Redstone capped by three annular clusters of small solid-propellant rockets, one inside the other, and the whole upper-stage assembly in a "washtub" airframe —it was this vehicle which orbited Explorer I, the first U.S. satellite, on Jan. 31, 1958. All told, six Jupiter-C vehicles were launched and three satellites resulted: Explorers 1, 3 and 4.

Another Army vehicle, the Jupiter, was fitted with the "washtub" of upper stages and was called the Juno 2. This vehicle was launched 10 times between Dec. 6, 1958, and May 24, 1961, and placed three satellites in orbit: Pioneer 4, which went into orbit around the sun on Mar. 3, 1959; Explorers 7 and 8 and 11.

The Jupiter, by the way, safely gave the two monkeys, Able and Baker, a brief ride into space on May 28, 1959.

First Cape Rocket Launchings

Last, but not least, there was the first and second rocket vehicles launched from the Cape—Bumpers 1 and 2.

The first-stage of these two-stage vehicles was a captured German World War II V-2 rocket, topped by an Army WAC-Corporal missile. Bumper I officially opened the Range with its flight on July 24, 1950; the Corporal climbed to an altitude of more than 25 mi. before falling back to earth. The second Bumper, launched five days later, flew somewhat higher.

Both flights set out to prove that a rocket vehicle could be staged and that a missile could be programmed from a vertical launch position to a horizontal flight attitude. They were successful.

Satellites

Since that eventful day in the Autumn of 1957 — Oct. 4, 1957, to be exact — when Sputnik 1, the first man-made satellite, threw open the doors to space, more than 600 other satellites have plied their trades all over the skies. Most — more than 400 — have been U.S. spacecraft, and a few have been built by the

Canadians, the British, the French and the Italians. The rest have been the property of the Soviet Union.

Four Major Categories

The well-organized U.S. space program breaks out its satellites into four major categories: scientific, applications, lunar-and-planetary, and non-orbital probes.

The scientific satellites are the Explorers (of which there are now more than three dozen different satellites), the Observatories, and the international satellites.

The applications spacecraft include the communications, meteorological (weather), navigational and geodetic vehicles.

The lunar-and-planetary satellites are, as the name implies, spacecraft designed to investigate either the earth's fellow-planets, the moon, or the far corners of space.

The non-orbital probes include a grab-bag of experimental gliders, special re-entry tests, and spacecraft which are launched straight up and which come straight down.

Scientific Satellites

So far, there have been more than three dozen Explorer satellites launched by the United States. These have ranged from the 31-lb. Explorer I to the 495-lb. Explorer 32. Their purposes vary as widely as their weights and shapes.

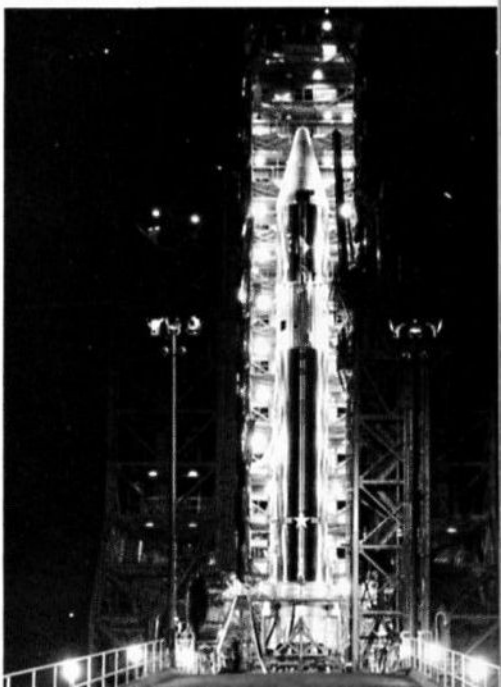
Explorer 1 discovered the Van Allen radiation belts. Explorer 6, launched Aug. 7, 1959, returned the first television pictures of earth taken by an orbiting satellite and was the first satellite to use solar paddles to re-charge its electrical batteries. Explorer 18, launched Nov. 27, 1963, confirmed that the earth had a "shock wave," similar to that created by a supersonic jet, along that edge of the globe facing the sun.

More detailed investigations of space are provided by NASA's three Observatory classes of satellites:

● Orbiting Astronomical Observatory (OAO). These 3,900-pound spacecraft, equipped with exotic telescopes and astronomical devices, are designed to provide man with a look at the stars that the earth's atmosphere now blocks. The devices aboard the OAO scan the stars in the ultra-violet, X-ray and gamma-ray segments of the spectrum, returning this data in coded electrical form over the telemetry links. There are no photographs, in the usual meaning of the term, sent down from the OAO. The first of four OAOs was launched by an Atlas-Agena Apr. 8, 1966, from the Cape, but the satellite mys-

Thor-Able, carrying a Transit navigational satellite.

Atlas-Centaur, being readied for launch, glistens in its gantry.

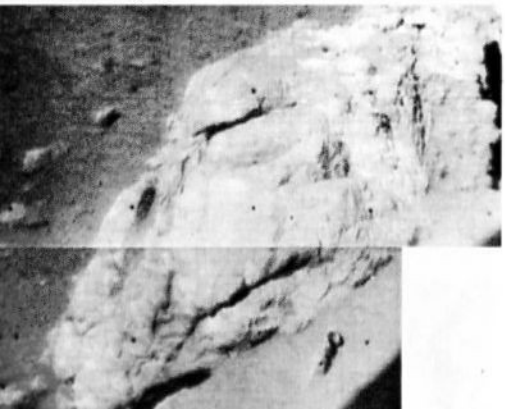


teriously failed the second day in orbit. Subsequent astronomical observatories, to be launched in 1968, 1969 and 1970, use the Atlas-Centaur launch vehicle.

● Orbiting Geophysical Observatory (OGO). Looking more like a mechanical bug than a highly-sophisticated satellite, the OGO is a standardized spacecraft that carries between 20 and 30 different experiments to study the complex relationship between the earth, the sun and the space environment. When all of its booms and antennas are extended, the OGO can measure as much as 50 feet long. It normally weighs between 1,000 and 1,100 pounds; of the first three OGOs, two were launched from the Cape by Atlas-Agenas on Sept. 4, 1964 and June 7, 1966. The other OGO, OGO-2, was boosted from Vandenberg Air Force Base by a Thrust-Augmented Thor Agena on Oct. 14, 1965.

● Orbiting Solar Observatory (OSO). Because the earth's atmosphere filters out much of the radiation streaming from the sun, man has in the past found it difficult to study certain solar activities that may have a bearing both on life here on earth and in spaceships sailing through space. To learn more about the sun, NASA developed the OSO series. Eight of these spacecraft will have perched high enough above the earth's atmosphere to have seen eight of the sun's 11-year cycle. The delicate instruments in the 450- to 650-pound satellites measure ultra-violet, X-ray and gamma-ray emissions from the sun, as well as spotting sunspot flares. The first OSO was launched from the Cape Mar. 7, 1962 by a Delta and the last spacecraft is expected to be flown in 1969.

Composite picture of a 6 x 18 inch moon rock was taken by Surveyor-1 June 3, 1966, as it sat on the moon and snapped pictures like a tourist.



Finally, the U.S. has embarked on an ambitious program of international cooperation in space satellites and has agreed to launch the satellites of other nations — such as the Canadian Alouette topside sounder and the two United Kingdom "Ariel" satellites.

Applications Satellites

Once the U. S. space program got started, it moved quickly to exploit two major areas of benefit to man: weather-watching and communications.

Nearly a score of weather satellites have kept a sharp eye on the cloud patterns on earth since the first Tiros (Television Infra-Red Observation Satellite) was orbited Apr. 1, 1960. Begun originally as a research-and-development project to determine if weather satellites from space were possible and practical, the Tiros program soon proved to be of greater value than anyone had anticipated. Over the next five years, nine more Tiros satellites were placed in orbit and they have been credited with saving untold millions of dollars in property damage and countless human lives by giving advance warning of dangerous storms.

Tiros was so successful that it led to the creation of two ESSAs—the Environmental Science Services Administration and the Environmental Survey Satellites. The ESSA agency uses the ESSA satellites (which are basically improved Tiros spacecraft) on a daily basis to provide weather data to participating organizations around the world. More than one million pictures of the earth's weather patterns have been snapped by Tiros and ESSA satellites so far.

Communications Satellites

The United States has been particularly active in the development and use of communications satellites to speed ever-increasing quantities of information around the world.

The first communications satellite was Echo-1, a 100-ft. diameter inflated balloon; it was orbited Aug. 12, 1960 and ground stations soon began to bounce radio signals off its shiny skin, like a garden hose directed against a beach ball. The signals scattered in all directions after striking Echo-1 and any ground stations within range could pick them up.

Today, internationally-owned commercial communications satellites—formerly called Intelsats (for International Telecommunications Satellite), but popularly

A three-stage Saturn I lies on its side in a huge hangar at the NASA center in Huntsville, Ala., where it was manufactured.

known as Early Bird (launched Apr. 6, 1965), Lani Bird (launched on Jan. 11, 1967) and Canary Bird (launched Mar. 22 , 1967)—are providing routine service between the United States, Europe and the Far East. These satellites are of the "active" variety, meaning that they receive messages transmitted up to them and then re-transmit the signals back down to other ground stations far distant from the originating terminal.

In between Echo-1 and the Intelsats, there have been a number of other communications satellites:

● Courier, an Army satellite launched Oct. 4, 1960. It was the first active-repeater communications satellite (comsat).

● Oscar-1, -2, -3 and -4, launched Dec. 12, 1961, June 1, 1962, Mar. 9, 1965, and Dec. 21, 1965, respectively. These are small (10 to 30 lb.) amateur radio operators' (hams) satellites.

● Telstar-1 and -2, launched July 10, 1962 and May 7, 1963, were products of the American Telephone & Telegraph Co. Telstar-1 transmitted the first live television pictures between the U. S. and Europe.

● Relay-1 and -2, launched Dec. 13, 1962 and Jan. 21, 1964, were RCA satellites built for NASA to test different aspects of comsats.

● Syncom-1, -2 and -3, launched Feb. 14, 1963, July 26, 1963, and Aug. 19, 1964, were the forerunners of today's Intelsats. They were placed in orbit about 23,000 mi. above the surface of the earth. At that altitude, they move around the earth in synchronization with whatever point on earth happens to be below; as a result, the satellite appears to be hanging stationary in space. These Syncoms, however, were not in orbit directly above the equator, so that they seem to move back and forth on a north-south line as the earth, with its tilted axis, rotates below them. Intelsats are positioned directly above the equator and so do not appear to move at all.

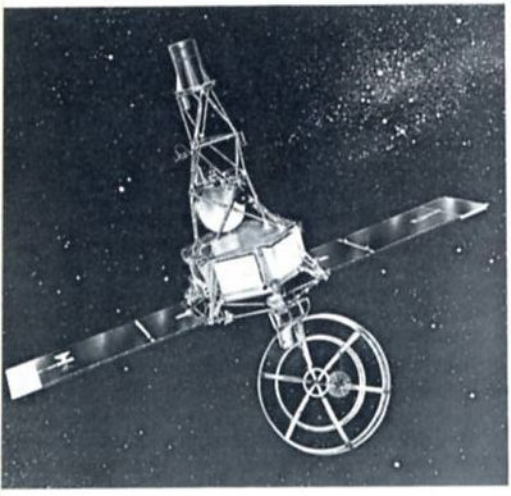
● Echo-2, a 135-ft. diameter balloon launched by NASA Jan. 25, 1964, for joint passive communications tests with the Soviet Union.

● Initial Defense Communication Satellite Program. This Defense Dept. comsat program is designed to string a series of satellites in orbit, about 20,000 mi. above earth. At that altitude, they will rotate about the earth at a rate slightly less than the earth's and so will appear to drift randomly. The purpose of this orbit, and the number of satellites involved, is to insure the high probability that a communications satellite will appear in the skies overhead whenever two ground stations, widely separated from each other, wish to communicate with each other. Seven IDCSP satellites were orbited by a Titan IIIC rocket June 16, 1966, followed by eight more (lofted by another Titan IIIC) on Jan. 18, 1967.

In addition, there have been several experimental comsats (Lincoln Laboratories Experimental Satellite, or LES, for one) orbited. The Applications Technology Spacecraft series, the first of which

Apparent similarity of the Martian and lunar surfaces is indicated by this picture taken of the planet Mars by the Mariner 4 spacecraft July 14, 1965, when it sailed within 8,000 miles of the Red Planet. Martian craters do not appear to be too much different from those observed on the moon.

The Mariner inter-planetary spacecraft.



Surveyor-1, as seen by Lunar Orbiter-3, Feb. 22, 1967, on the surface of the moon. Only the Surveyor's shadow could be seen distinctly by the Lunar Orbiter's cameras from an altitude of about 38 miles.

was flown Dec. 6, 1966, also carry a number of advanced communications devices that someday may appear on larger, improved Intelsats.

There also was Project Score, which was flown Dec. 18, 1958. While not a repeater comsat (messages could not be sent up to it for relay to other ground stations), it did carry a tape-recorded message from President Dwight D. Eisenhower to the world. The Score "satellite" was an entire Atlas test missile that boosted itself directly into earth orbit, much to the surprise of many workers on the Cape. Very stringent secrecy surrounded this project and only a handful of Administration, Air Force and industry personnel knew of the plan in advance.

Lunar and Deep Space Probes

The United States has conducted a creditable lunar and planetary spacecraft program, although the early years of these efforts were marked by delays and disappointments.

The U. S. has three lunar programs — Ranger, Surveyor and Lunar Orbiter — and two interplanetary projects—Mariner and Voyager. Ranger is finished, while Voyager has yet to fly.

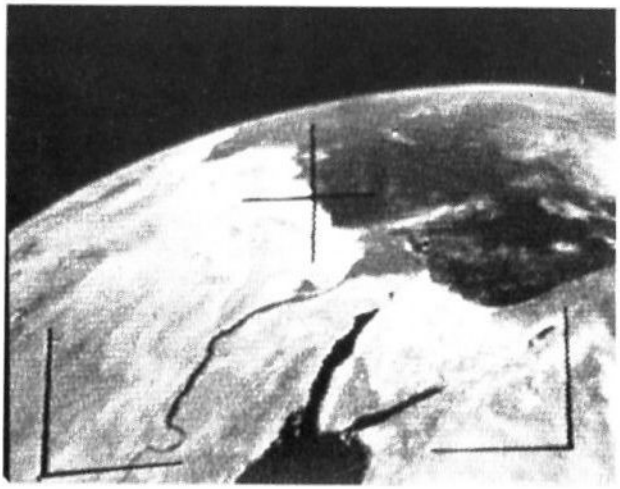
Ranger, started in 1959, was a television-equipped spacecraft that was to provide the first close-up pictures of earth's nearest neighbor, the moon. Rangers -1 and -2, launched during late 1961, were engineering test models not intended to fly to the moon. Rangers -3, -4, -5, and -6, however, were supposed to make it to the moon and send back pictures but each failed for different reasons.

Finally, on July 31, 1964, after an almost three-day trip from Cape Kennedy, Ranger-7 swept around the backside of the moon and dove, like a jet fighter plane, toward the half of the moon visible to earth. In the final 10 minutes before it crashed into the lunar surface, Ranger-7 sent back 4,308 pictures of the moon — most of them revealing details never before seen by human eyes.

Success is supposed to breed more success. It must be true, for Rangers -8 and -9 were equally as successful as -7, with Ranger-8 sending back 7,137 high-quality television pictures and Ranger-9 radioing back 5,814 clear frames on Feb. 17 and Mar. 24, 1965, respectively. The spacecraft were destroyed in the crash on the moon, but not before they snapped and sent their pictures. All Rangers were flown from the Cape by Atlas-Agenas.

The Surveyor spacecraft is meant to

he Surveyor spacecraft. ▶



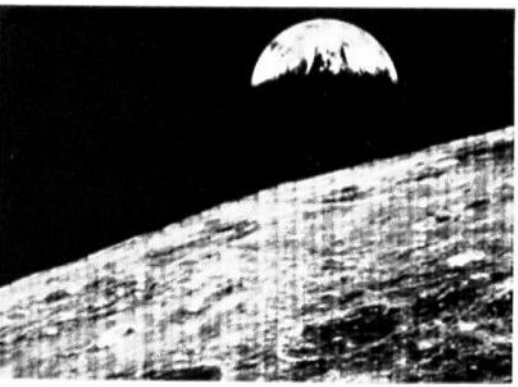
This is only one of several hundred thousand excellent photographs returned from space by the Tiros weather satellites; it shows the Red Sea, the Nile River, the Dead Sea and the Eastern Mediterrean Ocean.

continue the exploration of the moon where the Rangers left off, and to provide Apollo astronauts with some tentative idea of what they can expect to land on someday.

A three-legged machine, the Surveyor is designed to land softly on the moon and swing its television camera around to show what the lunar surface looks like from close-up. Surveyor-1, launched from here May 30, 1966, did precisely that.

In one of the most extraordinary displays of perfection, the Surveyor-1 snapped about 11,150 pictures of the region Oceanus Procellarum (Ocean of Storms), the area in which it had landed. The spacecraft continued to respond to commands radioed up to it for months after it should have quit operating.

Surveyor-2, launched from the Cape by another Atlas-Centaur Sept. 20, 1966, failed to complete its mission when one of its small vernier engines malfunctioned and the spacecraft could not be controlled properly. It crashed into the moon.



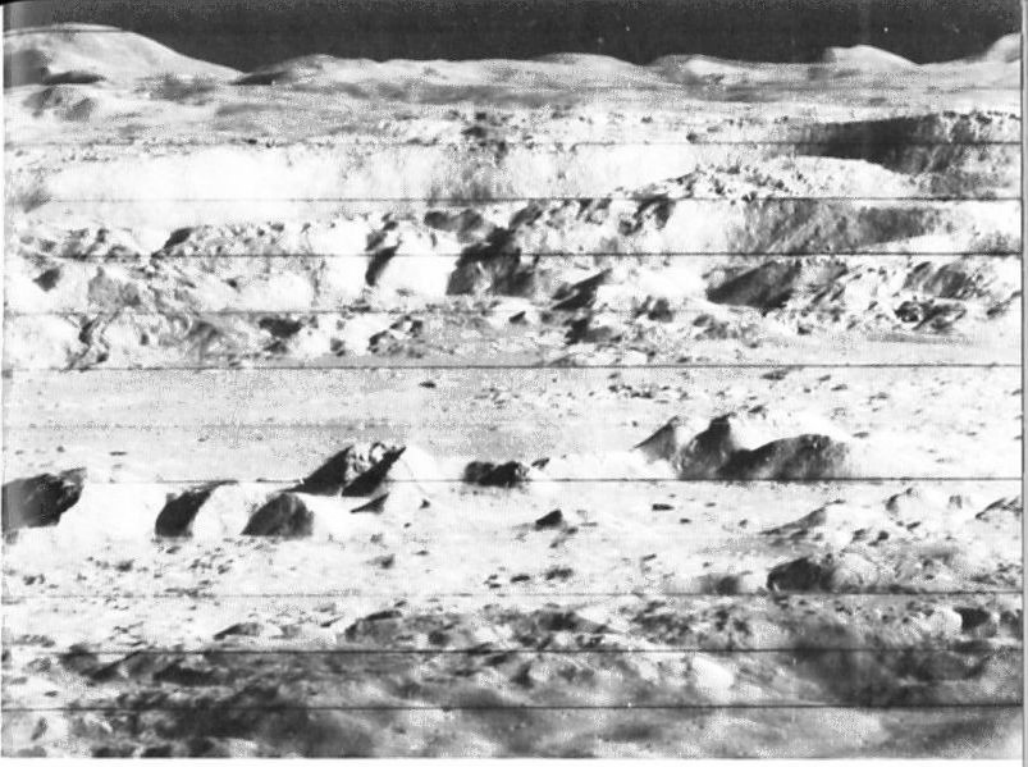
The first Lunar Orbiter looked back over its shoulder Aug. 23, 1966, and snapped this picture of the earth several days after it had arrived at the moon. Crater-scarred surface of the moon is visible in the lower part of the frame.

Surveyor-3 was more like the -1 spacecraft. Launched Apr. 17, 1967, it settled gently onto the moon almost three days later. In addition to taking pictures of the lunar area in which it had landed, Surveyor-3 also tested the nature and strength of the moon's crust with a small mechanical shovel. While the spacecraft's camera system watched, the small shovel—on the end of a "lazy-tongs" arm—dug into the soil. Scientists later said that the moon's top soil appeared to have the density of wet beach sand and pronounced it strong enough for astronauts to land upon it someday.

The Mariner series of spacecraft has centered its attention on the planets Venus and Mars.

Mariners-1 and -2 were aimed at Venus, while Mariners-3 and -4 were devoted to Mars. Mariner-1 was a failure, but Mariner-2, launched from here Aug. 26, 1962, came within 22,000 mi. of Venus on Dec. 14 that same year. The spacecraft's sensitive instruments radioed back to earth that Venus was a hot planet, with a surface temperature of approximately 800 degrees Fahrenheit.

Mariner-3 was a bust in its attempt to fly-by Mars, but Mariner-4, launched here Nov. 28, 1964, just 23 days after Mariner-3, was a resounding success. The 575-lb. spacecraft, carrying a camera,

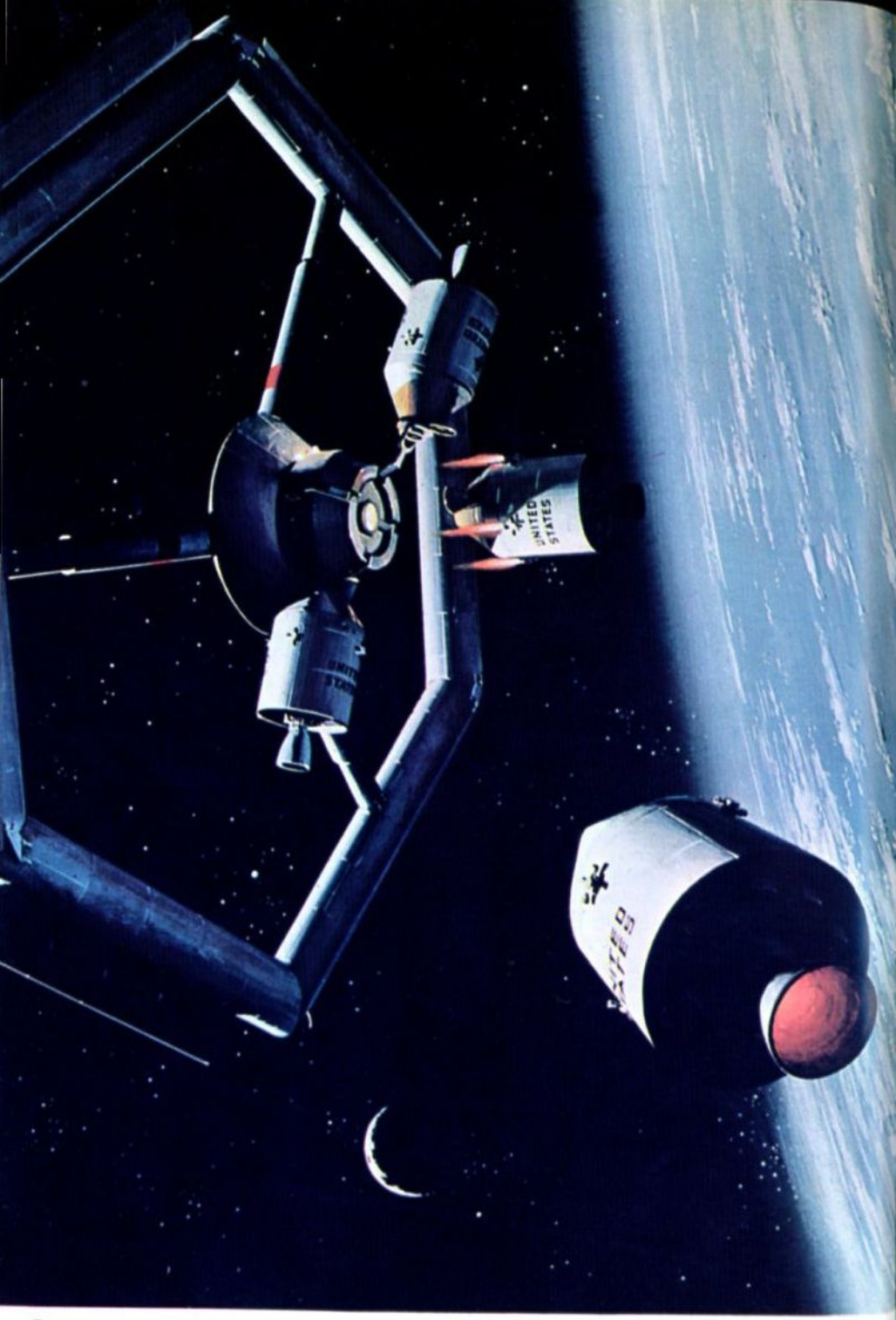


Called one of the most remarkable photographs ever taken, this picture of the crater Copernicus was taken by the Lunar Orbiter-2 spacecraft as it flashed 28½ miles above the surface of the moon Nov. 23, 1966. Lunar Orbiter was about 150 miles south of the crater when it snapped this picture, which gives some idea of the size of Copernicus. Area taken in by the frame is approximately 150 miles from the horizon at top to the base and 17 miles across.

came within 8,000 mi. of the red planet and snapped 21 pictures of that strange, hostile-looking body. There were no indications of life on Mars — although any life would have to be gigantic to be visible at a distance of several thousand miles — and the crater-pocked surface of the planet was very similar to photos taken of the moon.

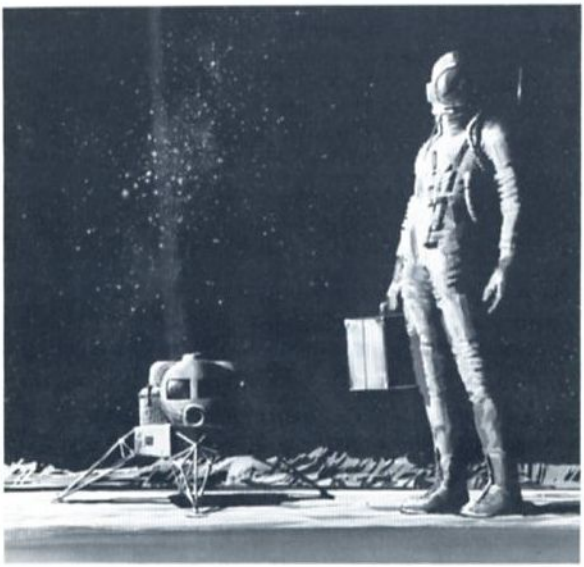
Voyager is a very ambitious U.S. program of unmanned planetary exploration in the 1970s. These spacecraft will be large—about 20,000 lb.—and will consist of several sections: the bus, which will contain all of the equipment necessary to operate the spacecraft for the many months it will be sailing through space; a propulsion module, which will be used to make course corrections on the way to Mars and other planets; and a landing capsule, which will separate from the rest of the Voyager and descend to the surface of the planet to conduct scientific investigations.

First photograph of the earth snapped from synchronous altitude (22,300 miles above the earth's surface) shows cloud patterns like marble grain; the picture was taken by the Applications Technology Satellite-1 Dec. 11, 1966 high above the Pacific Ocean. Baja California and part of Mexico and the southwest United States are visible in the upper right hand segment of the photograph.



Large space station with Apollo ferry vehicles.

Astro-repairmen work on their vehicle in space. ▶



Projects Apollo, Gemini and Mercury ... how the round trip to the Moon will be made ... future plans for man in space

Man in space

The ancient Greeks told the story of Icarus, a youth who fashioned a marvelous set of wings for himself. Unfortunately, Icarus flew too close to the sun and the wax which held his wings together melted. He fell and died.

Literature is filled with stories of men who magically flew and it would seem that there is something about flight that has always caught man's deepest interest.

But it was not until the end of the 18th century that man first was able to leave the surface of his planet for any length of time; a hot-air balloon was then the means of flight.

It took more than a century for man to acquire the technology that would enable him to advance to the next level of flight: powered, self-sustained motion through the air. The Wright Brothers, Orville and Wilbur, showed the world how to do it Dec. 17, 1903, at Kitty Hawk, North Carolina.

Since 1903, man has rapidly built a technology so powerful and so deep that he has begun to make the ancients' myths of flight through the heavens a reality. The challenge of flight, however, is not without its risks — as Icarus and many thousands of aviators since have proved.

Nor is space flight exempt from danger. The United States has lost six astronauts —Theodore Freeman, Charles A. Bassett, Elliott M. See, Virgil I. ("Gus") Grissom, Edward H. White, and Roger B. Chaffee — the first three in airplane crashes and the last three, the crew of the ill-fated Apollo-One, in a spacecraft fire during a ground test Jan. 27, 1967 here at the Cape. The Soviet Union lost Vladimir Komarov Apr. 24, 1967, when his Soyuz-1 spacecraft's landing system failed to work and he plummeted to the ground.

And yet man continues to fly — faster, higher and farther. He knows, as did his sailing ancestors of the 15th and 16th centuries, when they left Europe's comfortable ports to explore unknown lands, that the promise of a better, richer life awaits him, somehow, somewhere in space.

When space stations become a reality, and man lives in space for prolonged periods of times, his roles as repairman, observer, decision-maker, scientist and — who knows — perhaps passenger, will become clearer. We might have to wait until the year 2000 and the activities then taking place in space before we have the perspective with which to judge today's efforts.

The Apollo program is a long U.S. stride toward that future.

It is the project organized to meet the goal set by the late Pres. John F. Kennedy, shortly after he became the Chief Executive in 1961, of landing a man on the moon and returning him safely to earth before 1970.

The project had begun in 1960 as a study of the feasibility of flying a manned spacecraft around the moon on a reconnaissance mission. However, the study remained only a study during the final year of Pres. Dwight D. Eisenhower's Administration.

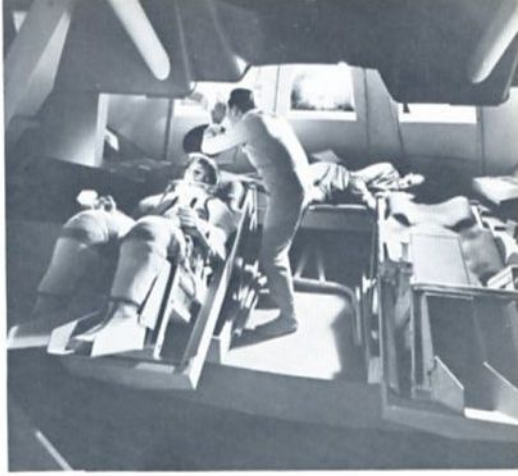
President Kennedy Recommends

On May 25, 1961, Pres. Kennedy stepped before a joint session of the U.S. Congress and told that body: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to earth. No single space project in this period will be more impressive to mankind or more important to the long-range exploration of space, and none so difficult or expensive to accomplish."

It was a challenging task to ask of the nation, coming as it did on the heels of the Soviet Union's smashing triumph six weeks earlier. The Soviets had placed the first man in space—Soviet Air Force Major Yuri Gagarin.

U.S. morale was low, despite Navy Cmdr. Alan B. Shepard's sub-orbital flight on May 5 to a distance of 300 mi. down the Atlantic Missile Range which had provided a temporary lift. The fact remained that the Russians had orbited a man completely around the world while the U.S. had gone only 1/80th of the way.

The U.S. was stung when Soviet Premier Nikita Khrushchev called Shepard's flight "a flea jump."



Apollo crew members in a wooden mock-up of the lunar spacecraft.

NASA Responds

This, then, was the atmosphere when the late President sounded the call. The National Aeronautics and Space Administration, which had been impatient to push ahead with the manned exploration of space, responded eagerly.

Several firms — General Electric, General Dynamics/Astronautics and Martin Co. — had been assisting the civilian space agency with studies of what the Apollo spacecraft should look like and how it should be designed. Taking these studies and some of its own studies made in-house, NASA set out to build up the industry team which would be required for such an ambitious undertaking.

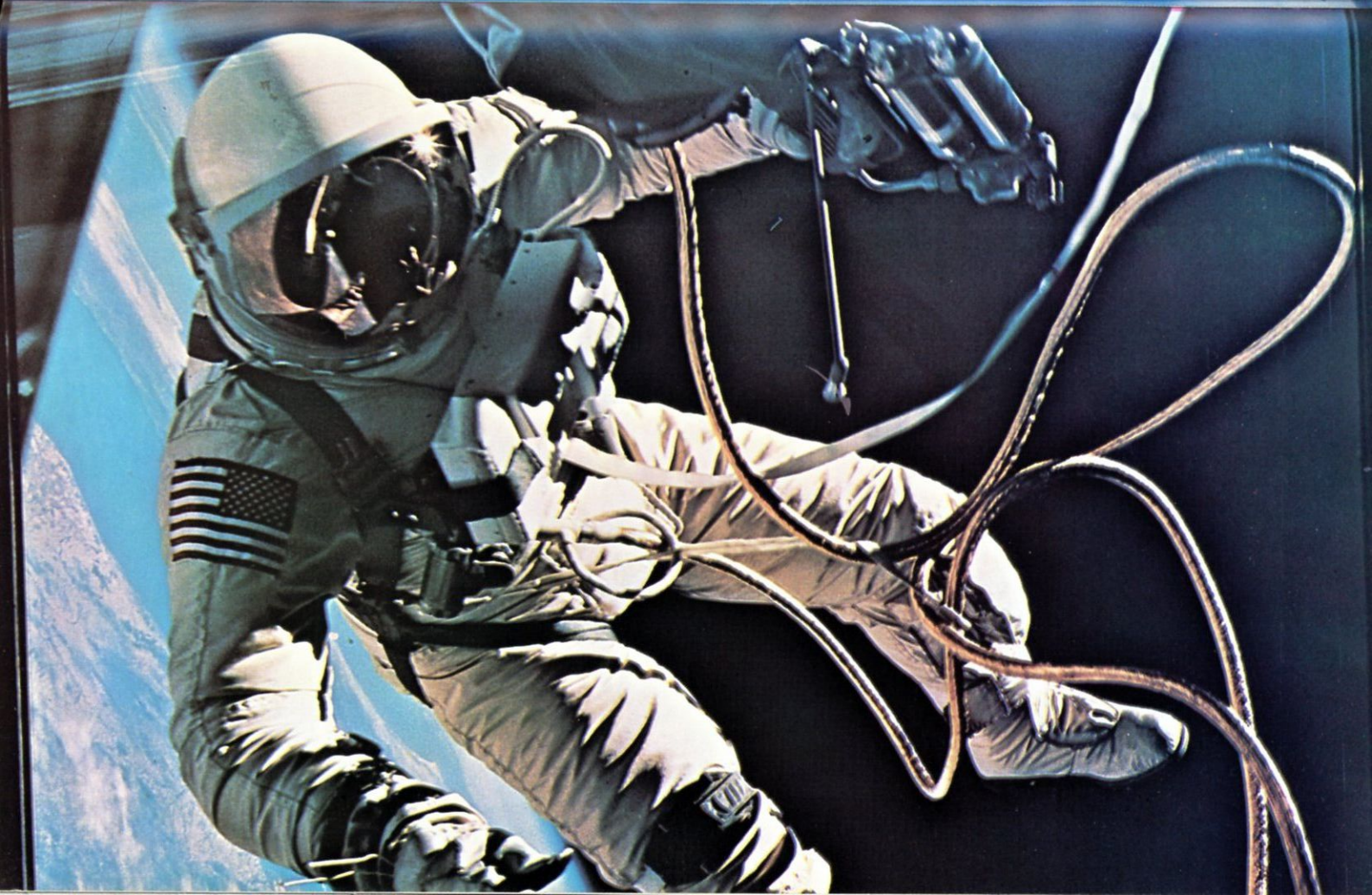
The agency held a three-day, closed-door session during a sweltering July week (1961) at its Washington, D.C., headquarters, and outlined the problems involved in landing a man on the moon.

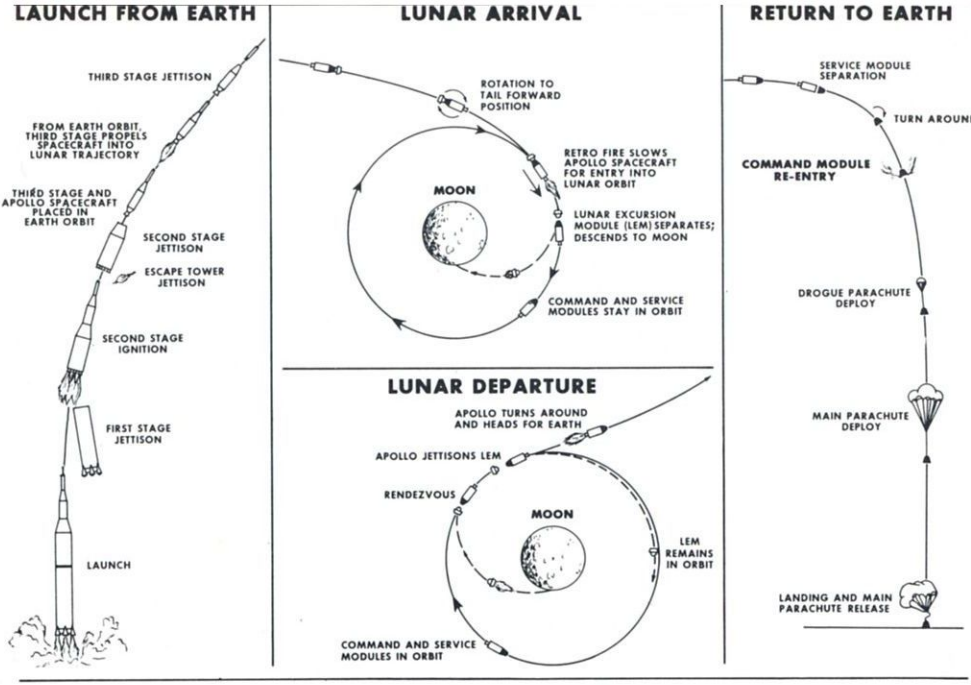
More than 1,000 representatives from U.S. industry attended. After this and several subsequent meetings, NASA asked 15 firms to submit proposals to build the Apollo three-man spacecraft. Five companies responded in October and in November, NASA picked North American Aviation, Inc., as the prime contractor. Work began in earnest*.

Which Way To The Moon?

One question about the mission, however, remained unanswered — what was the safest, most reliable, most economi-

*Earlier, in September, the agency announced that it was re-organizing the management of its manned space flight programs and was establishing a new center — the Manned Spacecraft Center at Houston, Tex. — to be responsible for these programs. The center was built around the nucleus of the Space Task Group, which had been based at NASA's Langley Research Center, Va. and which had been managing the Mercury project.




LAUNCH FROM EARTH
THIRD STAGE JETTISON
FROM EARTH ORBIT, THIRD STAGE PROPELS SPACECRAFT INTO LUNAR TRAJECTORY
THIRD STAGE AND APOLLO SPACECRAFT PLACED IN EARTH ORBIT
SECOND STAGE JETTISON
ESCAPE TOWER JETTISON
SECOND STAGE IGNITION
FIRST STAGE JETTISON
LAUNCH
LUNAR ARRIVAL
ROTATION TO TAIL FORWARD POSITION
RETRO FIRE SLOWS APOLLO SPACECRAFT FOR ENTRY INTO LUNAR ORBIT
MOON
LUNAR EXCURSION MODULE (LEM) SEPARATES; DESCENDS TO MOON
COMMAND AND SERVICE MODULES STAY IN ORBIT
LUNAR DEPARTURE
APOLLO TURNS AROUND AND HEADS FOR EARTH
APOLLO JETTISONS LEM
RENDEZVOUS
MOON
LEM REMAINS IN ORBIT
COMMAND AND SERVICE MODULES IN ORBIT
RETURN TO EARTH
SERVICE MODULE SEPARATION
TURN AROUND
COMMAND MODULE RE-ENTRY
DROGUE PARACHUTE DEPLOY
MAIN PARACHUTE DEPLOY
LANDING AND MAIN PARACHUTE RELEASE

Sequence of major events in the Apollo lunar landing mission.

cal way of getting to the moon?

An ad-hoc committee under Dr. Nicholas E. Golovin studied the question for three months and, in December, submitted a majority report recommending a three-segment, 150,000 lb. spacecraft which would be assembled by rendezvous in earth orbit before flying to the moon.

There, the entire spacecraft, minus only the fuel it had burned to kick itself onto a translunar trajectory, would lower all three segments onto the lunar surface. The bottom-most stage would contain a descent engine to lower the entire craft onto the moon. The middle segment would be another propulsive stage, smaller than the bottom one, and would be used to launch the top segment — the manned cabin — on a return trajectory back to earth.

Lunar Orbit Technique

A minority report endorsed the use of rendezvous in the mission but suggested that the technique be used in lunar, rather than earth, orbit.

In this way, the minority report argued, the landing could be made by a small light-weight vehicle built especially for that purpose; there was no real point, it continued, to bring all of the hardware and fuel needed for the return flight to earth down to the lunar surface and then launch it off again. That in itself required more fuel.

The best way, therefore, to accomplish the task of rendezvous and the mission was to leave all the systems intended for earth-return flight in lunar orbit, while the specially-built landing craft went down to the moon with part of the crew.

With this approach, the minority report concluded, the manned lunar landing could be accomplished by a spacecraft weighing only 90,000 lb. — a weight that a single advanced Saturn could handle. The 150,000-lb., earth-orbital Apollo would have required two Saturn vehicles to lift it into orbit, in two 75,000-lb. segments.

The arguments raged back and forth for more than seven months before NASA, in an unusual move, decided in favor of the minority recommendation in July, 1962, and made known its decision in a public conference. A competition then was held to select a manufacturer for the special lunar-landing craft, later to be officially called the "lunar excursion module," or LM. In December, 1962, NASA chose the Grumman Aircraft Engineering Corp. to build the module.

◀ **Edward H. White floats effortlessly in space, June 3, 1965.**

The first two classes of astronauts. Seated, left to right, Gordon Cooper, the late Virgil Grissom, Scott Carpenter, Walter Schirra, John Glenn (now resigned from the program), Alan Shepard and Donald Slayton. Standing, left to right, the late Edward White, James McDivitt, John Young, the late Elliott See, Charles Conrad, Frank Borman, Neil Armstrong, Thomas Stafford and James Lovell.

The Spacecraft

By the end of 1963, the design of all three spacecraft modules had been fairly well firmed up:

• **Command module** is the combined cockpit and crew quarters in which the three Apollo astronauts will spend most of their time. About 12 ft. tall and with a diameter of about 13 ft. (all three modules have the same basic diameter), the module weighs about 10,000 lb. It includes aircraft-type portholes for pilot viewing, as well as instrument panels, computers, star-tracking telescopes, bunks, a small galley, toilet facilities, and a reaction control system for small maneuvers.

During the early phase of flight it carries a 15 ft.-tall, 150,000 lb.-thrust solid-propellant escape motor, built by the Lockheed Propulsion Co., on a derrick-like structure mounted on its nose. In the event of any launch vehicle trouble, the motor instantly pulls the astronauts and their command module to safety.

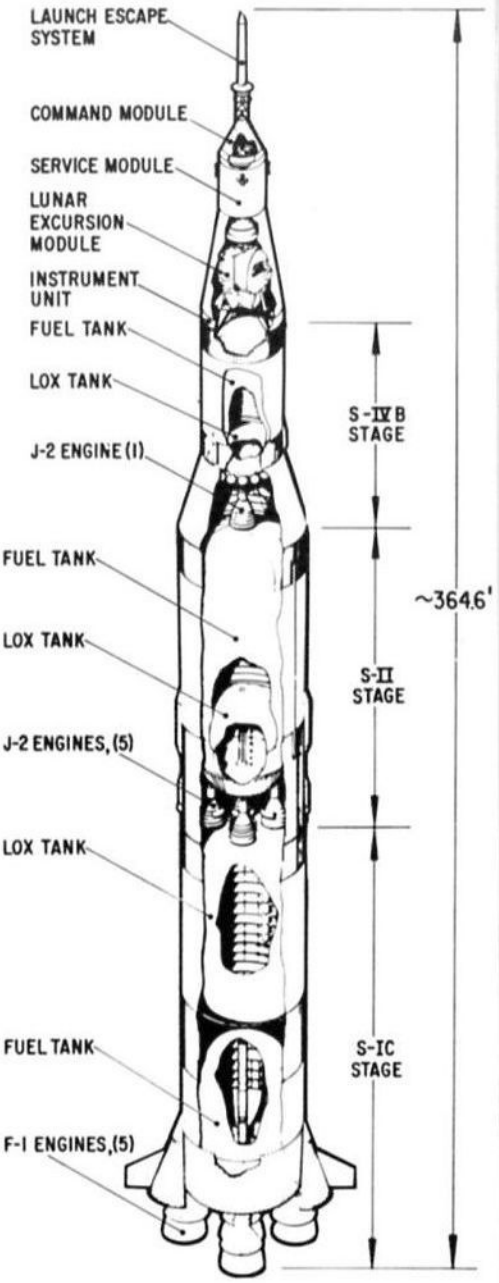
• **Service module,** also built by North American, is the propulsive stage which will propel the complete spacecraft into and out of lunar orbit. It also carries quite a bit of equipment: the electricity-producing fuel cell and its propellants, breathing oxygen reservoir, communications antenna, a 22,000 lb.-thrust Aerojet-General Corp. liquid-fueled engine and the propellants to feed it.

The module stands about 23 ft. tall, weighs about 47,000 lb. fully-fueled and will be jettisoned at the conclusion of the flight, just before the command module re-enters the earth's atmosphere.

• **Lunar module** is the "bug" which two Americans will ride down to the surface of the moon in the near future.

The odd-looking craft consists of two parts: a descent stage, which lowers the entire vehicle gently to the moon's surface, and an ascent stage, which detaches from the base of the Lunar Module (LM) to fly the two-man crew back to the command-service module in lunar orbit. The retractable landing gear extends out to a radius of 13½ ft. to provide a stable touch-down, regardless of the irregularities of the lunar surface.

The LM stands about 20 ft. tall and weighs about 27,000 lbs. A cylindrical fairing wraps around the LM to protect it during boost flight, as well as to structurally bridge the gap between the third stage of the Saturn V and the service module of the spacecraft. It



Cutaway artist's drawing of the three-stage Saturn V and the three-module Apollo spacecraft.

Water-impact tests of the Apollo command module, dropped from top of tower.

weighs about 3,000 lb. and the LM is attached to it during the early phase of the flight.

This is the way that tne first U.S. crew will reach the moon:

Liftoff To The Moon

The gigantic Saturn V launch vehicle slowly lifts off its launch stand with a thunderous roar that rattles windows 10 mi. away and which might be heard as far as 50 mi. away. Americans watching the beginning of this historic flight on their television sets may feel their pulses quicken as the vehicle seems almost to be hovering above the stand, but soon it gathers speed as the 7.5 million pounds of thrust in the first-stage engines push it upward.

First Stage Jettisoned

At an altitude of about 200,000 ft., the first-stage abruptly shuts down and is discarded, as the second stage ignites and continues to push the three men and their spacecraft to ever faster speeds. At more than 100 mi. altitude, the second stage shuts down and it, too, is cast aside now that its work is done.

The third stage then ignites and burns just long enough to give the spacecraft (which has rid itself of the escape motor during second stage operation, after the most critical part of the flight has safely been passed) the velocity required to fall into earth orbit.

Earth Orbit Obtained

Then, still attached to the spacecraft, the third stage shuts down and both it and the Apollo enter into a temporary earth orbit.

Computers back on earth determine the correct time for the third stage to fire again, so as to shove the spacecraft out of earth orbit and place it on an intersecting course with the moon. Just as a hunter always aims a little bit ahead of a flying duck, so will the second firing of the third-stage "lead" the spacecraft to a point in space where the moon will be about 70 hr. after the lift-off time.

Moonbound — LM is Readied

Now bound for the moon, the astronauts trigger explosive circuits which break the shroud surrounding the LM and kick the pieces off to one side.

Gently, the command pilot eases the command and service modules away from the LM, still attached to the third stage, and flies about 50 ft. ahead. There he turns the command-service module completely around so that it now faces the LM and flies back to slip the nose of the command module into the top hatch of the LM.

Only after this step — called the "turn-around" maneuver — is completed, is the third-stage jettisoned.

The turn-around maneuver serves two purposes. First, it clears the service module's 22,000-lb. thrust Aerojet-General Corp. engine for use (during the boost phase of the flight, the LM sits directly below it) and, secondly, it allows the astronauts to pass from the command module into the LM without going out into space.

The Three Day Flight

During the three-day flight to the moon, the men work in over-lapping shifts, with two "on" while the third is "off." At least one man has his protective space suit on during a shift, but the other two probably take theirs off and move about the capsule in comfortable long underwear-like garments.

For certain important tasks, such as the mid-course corrections, all three men are at their seats to perform their specific functions: one man is the Command Pilot, who pilots the vehicle and is in charge of the mission; another is the Senior Pilot, who flies the spacecraft during the commander's off-duty hours; and the third Pilot, who handles navigation and communications systems.

Each man, however, is so well-trained that he can do all three jobs, if an emergency arises.

The mid-course corrections come at certain times during the flights as ground-based tracking radars follow the Apollo and constantly calculate its path with respect to the moon. The process is one of continuous refinement, but rather than have the crew make small course corrections every few minutes, the changes are saved up for one large correction about every 15-20 hr.

Lunar Orbit Obtained

Shortly after the third day out, the Apollo is caught by the moon's gravitational field and begins to speed toward the earth's only natural satellite. At just the right time, the service module engine is fired (the spacecraft is flying backward) to prune enough speed from the vehicle to permit it to enter an orbit around the moon.

The spacecraft commander continues to use the engine in short, pulsed firings until his instruments tell him that he is in a precise circular 92-mi. high orbit above the lunar surface. Then he and the pilot crawl through a connecting tunnel into the lunar excursion module.

LM Descent To The Moon

After first making certain that all LM systems are in working order, the commander fires small thrusters on the landing craft to back it away from the command module. Using the descent stage's 10,000-lb. thrust engine, he puts the LM into a diving orbit which comes as close to 50,000 ft. above the lunar surface before pulling out and climbing back to 92 mi.

In this way, both LM and the command-service module return to the same 92-mi.-high point every 2 hr. — so that the LM crew can make it safely back to their mother spacecraft even if the lunar landing vehicle should fail.

Selecting Lunar Landing Site

But if everything progresses normally, the landing crew makes several orbits around the moon and surveys possible landing sites.

They select the most-likely looking plain on the moon and again turn on the descent engine. With the sun behind them, so as to provide the best possible shadow contrast and show up hidden ravines or large boulders, the crew descends down to about 1,000 ft. above the moon and there hover, like a helicopter.

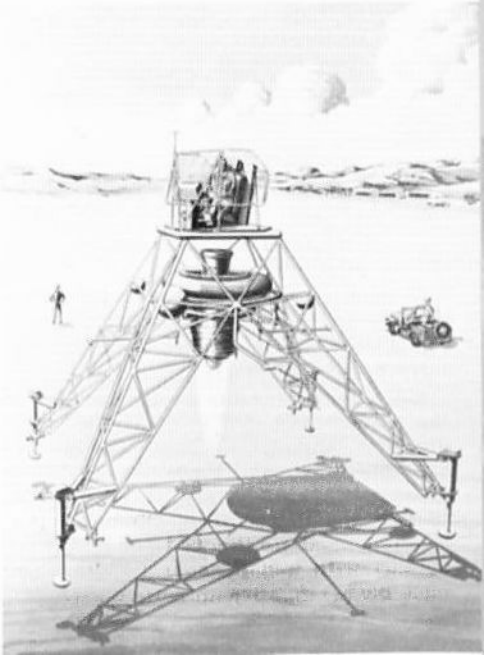
They carefully study the landing area which they have selected — is it as smooth and solid as it appeared at 50,000 ft.? How deep is that depression over there? Which way does the surface slope?

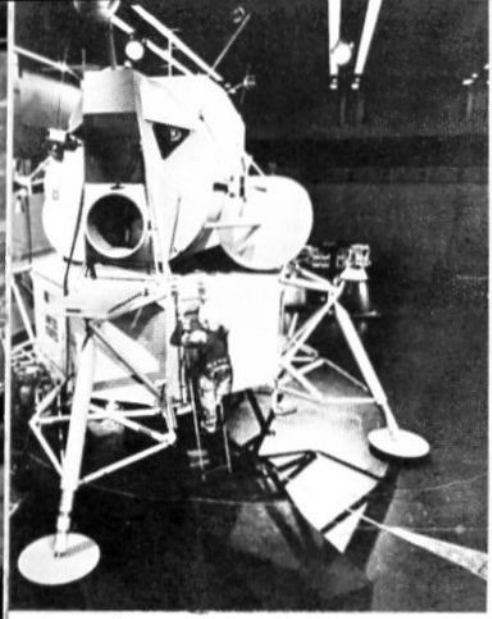
LM Lands On The Moon

Cautiously, slowly, they let the LM down. The Command Pilot stares out the small triangular window before him at the lunar surface, while his partner keeps his eyes glued on the LM's instrument panel. Then the exhaust from the descent engine strikes the lunar surface and sends up great clouds of dust; the Command Pilot has a hard time seeing the surface. His hand rests on the engine's throttle, ready to slam it forward to "full power," if necessary, to drive the LM back to the safety of higher altitudes.

Feeling a slight bump as the big circular pads on the ends of the landing gear hit the moon, the Command Pilot

Lunar Descent practice rig





An engineer climbs a ladder on the side of the first full-scale model of the LM toward the forward hatch, while his team-mate watches him through one of the craft's triangular windows.

eases back on the throttle until he is certain that the landing has been successful. He then shuts off the engine.

First things come first and the crew immediately prepares to take off, for it is more important that they return safely to earth than that they walk on the moon's surface. The Command Pilot and co-pilot run through the launch countdown of the ascent stage, bringing it down to the point of engine ignition. There they stop.

Assured that they can now take off from the surface, they are ready to explore that long-dead satellite, the moon.

First Man On The Moon

The pilot, with a small life-support back-pack strapped to his back, snakes his way out through the forward hatch and scrambles easily down a ladder to the surface of the moon.

He stoops to examine the nature of the surface and if it is dusty, he might dig for a while to see how far down the dust layer extends. He walks about the moon, always under the visual observation of the spacecraft commander, who has remained in the LM, and in voice contact with him through a radio in his back-pack.

If nothing untoward happens after an hour or so, the command pilot also steps out onto the moon and the two men together begin the exploration of the moon.

They pick up rock and soil samples and drop them in small sterile plastic bags. They make photographs — of each other, of the lunar surface, of the many stars visible to them and, of course, of their native earth. They set out some equipment — perhaps a seismometer or a radiation detector — and connect it to a small transmitter, so that these instruments will be able to send data back to earth after the men leave.

When the time does come to leave the moon — anywhere from 4 hr. to one day after the landing — the men climb back into the LM with their bags of samples, cameras and notebooks and store them in a special bin.

They then go about the business of rejoining their fellow astronaut who has remained in lunar orbit aboard the command and service modules.

LM Is Launched

Using the LM's tracking radar and computer, the crew plots the path of their spacecraft and launch themselves at the exact moment called for by the computer; they use the descent stage of the LM as a launch stand — only the ascent part leaves the moon.

The two men and their ungainly-looking craft climb rapidly to an altitude of 50,000 ft., where they level off and go into a temporary parking orbit. There they re-track and re-plot the orbital path of the mother spacecraft and again turn on the LM's engine at the time called for by the computer. They now fly a steep ascending curve that takes them to a rendezvous with the command-service modules; they wind up slightly ahead and a little above the mother ship.

Command Module Rendezvous

Then, by small flick-firings of the small thrusters located around the LM, the Command Pilot eases his landing vehicle up to the nose of the command module and the two lock together with a gentle bump.

The men pick up all the samples, the cameras and notebooks and, after one last look around the vehicle which has taken them down to the moon, they slip through the tunnel back into the command module, where the senior pilot happily pounds them on the back.

The critical turn-around maneuver on the way to the moon; the nose of the Apollo command module now connects to the top of the LM.

Homeward Bound

They disconnect the LM and push it away; it is not going back to earth. The commander then fires the service module's big engine and the Apollo picks up speed — so much that it slips from the moon's gravitational grip. The men are homeward bound.

As on the way out, they must make mid-course corrections. But this time, the corrections take on a new significance — the men are aiming for a 40-mi. deep, 300-mi. wide corridor in the earth's atmosphere. It sounds big enough, but from the distance of the moon it is like trying to throw a penny through the mail slot of your front door — from two streets away.

If they overshoot this narrow target, they skip off the top of the earth's atmosphere like a flat rock skipped along the surface of a lake and soar back out into space, perhaps so far out that all their oxygen will be used up before the command module (it has dropped the service module just before encountering the earth's atmosphere) can swing back again in a huge orbit around the earth.

If the crew undershoots, the command module will be subjected to deceleration loads for which it was not designed — nor was the human body. Spacecraft and astronauts will simply be crushed under these enormous loads.

Re-entry And Recovery

But all goes well on this mission. The spacecraft's guidance system, aided by the tracking radars on earth, leads the vehicle right down the middle of the corridor. Small jets around the conical after-body of the command module give the commander the ability to maneuver his vehicle during the descent and he uses these to "fly" his spacecraft as close as he can to the recovery forces waiting on the ocean below.

Below 100,000 ft., a cluster of three large parachutes billow out from the top of the module and the spacecraft gently floats to the waves. Helicopters are on the scene within minutes and frogmen parachute into the water alongside the spacecraft, attaching floatation bags to it. Soon, a Navy ship steams up and lifts the men, still inside the module, onto the deck. Hatches are opened and the three Americans — two of whom may well have been the first men ever to set foot on the moon — step out into the bright sunlight.

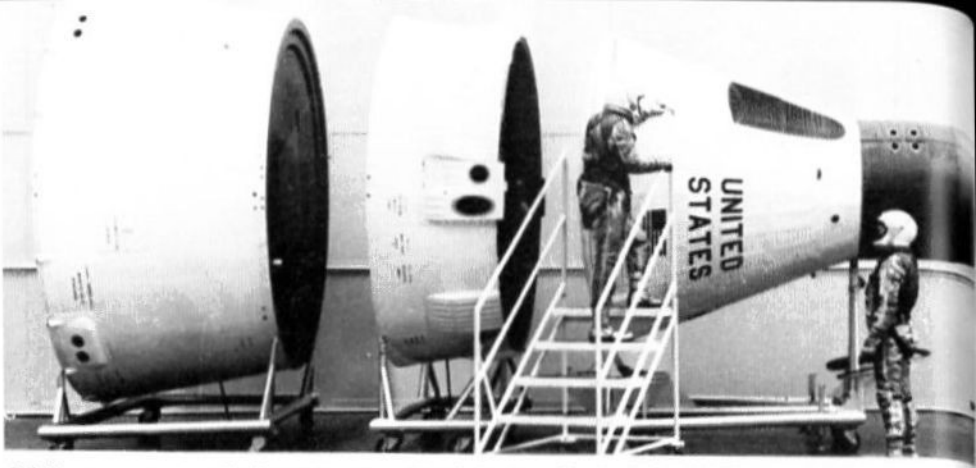
The mission is over.

Apollo Test Program

NASA has laid out a comprehensive test program, to flight-certify the Apollo spacecraft and its Saturn V launch vehicle, leading up to the lunar landing attempt.

The first step was to insure that the Uprated Saturn 1 launch vehicle was a safe carrier for its human cargo. Toward this end, the space agency set aside the first three boosters for unmanned flight tests. Each was heavily instrumented so that engineers could later determine, from the data radioed back to ground stations, exactly how all systems worked and if their performance was such man could entrust his life to them.

On Feb. 26, 1966, the initial flight phase of the Apollo program got underway when



Major segments of the two-man Gemini capsule include (left to right) the equipment section, retrorocket section, manned cabin and (black unit on nose of the cabin) re-entry control and radar sections. Segment at far right is a mock-up of the Agena docking adapter.

the Apollo/Uprated Saturn 1-201 (AS-201) vehicle — 224-ft. tall and weighing nearly 1.3-million lb.—thundered upward from Launch Complex 34 here. The two-stage booster shoved an unmanned Apollo spacecraft, crammed with measuring equipment, on a long ballistic arc that was just below orbital altitude and velocity; the purpose of this up-and-down ride was twofold:

- Prove that the Uprated Saturn 1 launch vehicle performed as it was designed to.
- Demonstrate that the Apollo spacecraft's heat shield could take the searing heat of re-entry successfully and still keep the interior of the command module — where three men would someday be — comparatively cool.

NASA quickly followed this successful first flight with an AS-203 vehicle—meant to be the third unmanned test craft, but which was moved ahead in the flight sequence when the AS-202 vehicle developed some minor troubles.

The Apollo/Uprated Saturn 1 203 vehicle carried no spacecraft when it was launched July 5, 1966. Instead, it orbited its own second stage — the S-4B — filled with about 20,000 lbs. of liquid hydrogen in an experiment to find out what happens to this extremely cold, very lightweight rocket propellant in zero-gravity. The answer to this question was of vital importance to the later phases of the Apollo program, for the moon-bound crew will spend upwards of several hours in earth orbit before restarting the S-4B for the final push to the moon.

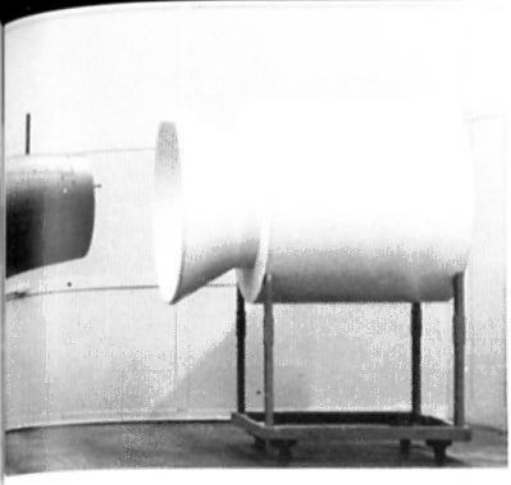
Test data later showed that NASA had correctly calculated what was needed to control liquid hydrogen under weightless conditions. The AS-203 mission was also rated a clear success.

The Apollo/Uprated Saturn 1 202 (AS-202), which had lost its time at bat earlier in the year because of technical difficulties, finally flew on Aug. 25, 1966. Like its AS-201 counterpart, it carried an unmanned Apollo spacecraft in a double-barreled test of launch vehicle and spacecraft heat shield.

But where the AS-201 booster had rammed its spacecraft back down into the earth's atmosphere to expose the cone-shaped capsule to very high temperatures for a short time span, the AS-202 vehicle lofted its empty Apollo halfway around the world into the Pacific Ocean. The purpose of this second test was to see if the Apollo heat shield could take the punishment of lower re-entry temperatures over a longer time period.

The spacecraft and the launch vehicle came through that final test with flying colors and soon thereafter, NASA announced that everything was now ready to begin manned flight operations with the next mission—Apollo/Uprated Saturn 1 204 (AS-204).

But AS-204 never flew as it was meant to be flown. Originally scheduled to be launched in late 1966 with Grissom, White and Chaffee at the controls, it ran into one



exasperating snag after another and the launch date kept slipping. The mission was set for Feb. 20, but the Jan. 27 fire inside the Apollo 204 spacecraft made it a meaningless date.

Although stunned by the tragedy, the space agency refused to throw in the towel. A blue-ribbon committee of experts was formed to investigate the fire and, after studying the incident for more than two months and sifting through enormous quantities of data, submitted its findings in early April to James E. Webb, the Administrator of the National Aeronautics and Space Administration, to Congress, and to the American public.

The review board said that the exact cause of the fire probably would never be known, but it expressed belief in a theory that the fatal blaze began when the insulation on some electrical wires was rubbed off and a short-circuit then occurred — somewhere to the left and below of veteran Mercury and Gemini astronaut Grissom. Once the fire got started in the pure oxygen environment then circulating through the capsule, the investigators concluded, the three astronauts didn't stand a chance to escape.

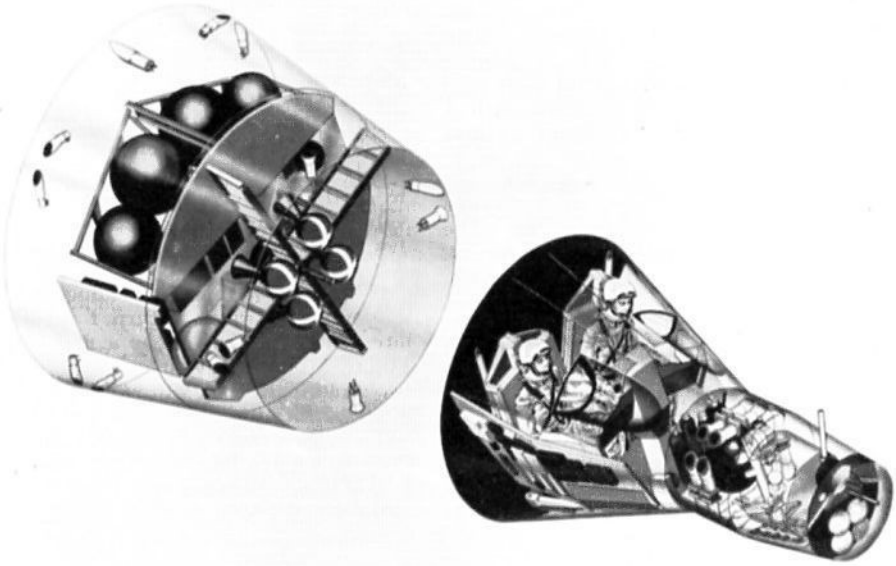
The board's final report was a severe reproach to the space agency for certain design features in the spacecraft, management control over the development of the spacecraft, and test practices

Instead of being a year in which the initial momentum of the Apollo program was sustained, 1967 instead became a year in which the space agency had to retrace quite a bit of engineering ground. The Apollo spacecraft had to be re-worked so that once again men could climb into it with confidence. As a consequence, manned flight operations slipped to 1968.

Schirra — First To Fly All Three

On May 9, 1967, NASA Administrator James E. Webb told the Congress how the space agency planned to get the Apollo program back on the track. He said that the crew of Walter M. ("Wally") Schirra,

Transparent view of the Gemini shows both pilots and all major systems.



Apollo-One crewmen Roger Chaffee, Ed White and Gus Grissom (left to right) were lying on their couches like this when the fire that claimed their lives broke out Jan. 27 at Cape Kennedy. The three astronauts are seen here inside the Apollo mission simulator, a space age equivalent of a Link trainer. The spacecraft's hatch is visible directly behind White's helmet.

Donn F. Eisele, and Walter Cunningham had been selected to fly the first manned Apollo mission. It was planned to be an earth-orbital flight, using an Uprated Saturn 1 launch vehicle.

Schirra, a Navy Capt., thus became the first U.S. astronaut to fly all three manned spacecraft — Mercury, Gemini and Apollo. For Eisele, an Air Force Major, and Cunningham, it would be their first space flight. These three astronauts had been the back-up crew to Grissom, White and Chaffee.

Named to be the new back-up crew were Thomas P. Stafford, an Air Force Lieut. Colonel and a veteran of both the Gemini-6 and -9 space flights, John W. Young, a Navy Commander and veteran of both the Gemini -3 and -10 missions, and Eugene A. Cernan, also a Navy Commander and a veteran of the Gemini-9 flight with Stafford.

Spacecraft Is Improved

Webb told Congress that the spacecraft would be modified during 1967 to eliminate the threat of fire. Certain combustible materials inside the Apollo were to be replaced with less flammable materials, he said, and a quick-opening hatch (less than 2 sec.) would replace the original hatch that took the better part of 60 sec. to open. The head of the space agency also said that Schirra, Eisele and Cunningham would make their flight within the first three months of 1968, but many observers thought this was an overly optimistic forecast.

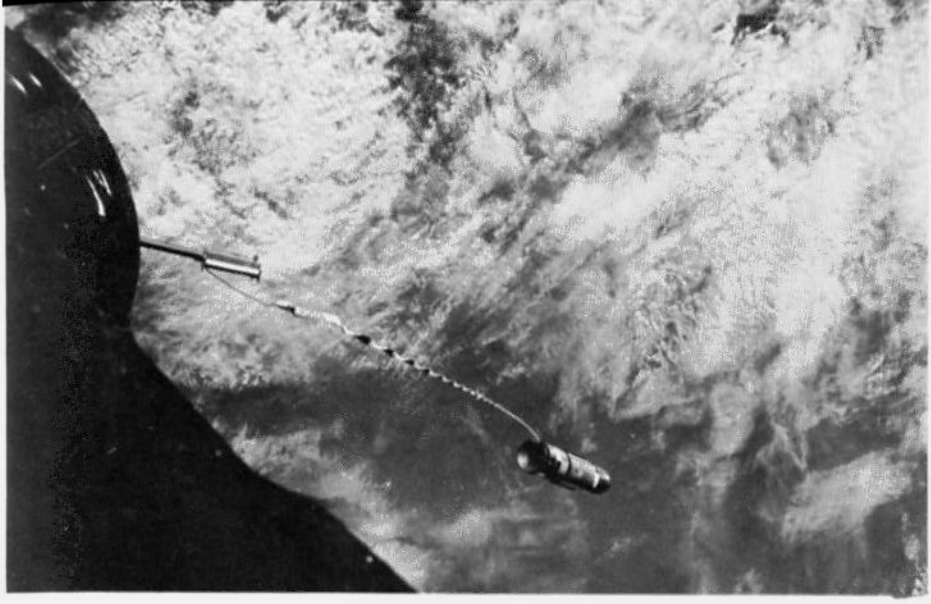
But not all Apollo flight operations came to a standstill after the Jan. 27 accident. The space agency continued to press ahead with its plans to fly the first two unmanned Saturn V rockets on missions similar to those flown by the first two unmanned Uprated Saturn 1s.

But where the Uprated Saturn 1s qualified the Apollo's heat shield at re-entry velocities associated with earth orbital flights (17,500 miles per hour), the two Saturn Vs — AS-501 and AS-502 — were to sling the empty Apollos several thousand miles into space before they returned to earth at speeds approaching those involved with lunar flights (25,000 miles per hour).

First Lunar Module Flight

NASA also planned to conduct the final unmanned Uprated Saturn 1 mission in late 1967. This was to be a flight of the Lunar Module, the space rowboat that two Americans soon will ride down to the lunar surface.

The space agency is still confident that it can meet the late President Kennedy's goal of a manned lunar landing by the end of the decade. Saturn V rockets and Apollo spacecraft should come together in 1968



Gemini 12 astronaut James A. Lovell snapped this beautiful picture of his Agena target stage in space, Nov. 11, 1966.

to form an effective, dependable space vehicle team. After one, or perhaps two, manned flights of the Apollo/Saturn V vehicle in orbit around the earth, where the moon mission will be rehearsed, the agency expects to be able to give the green light for an attempt to land on the moon.

General Electric's Role

Apollo is the largest single program ever undertaken by this nation. It is so large, in fact, that NASA decided to hire one firm — the General Electric Co. — to provide assistance in three areas: reliability, checkout and systems integration.

In this first area, GE is providing studies of all the parts of the Apollo/Saturn V vehicle so that NASA can more precisely determine the probability of each mission's success.

The company also is providing a family of automatic test equipment which will be used to ready the Apollo/Saturn V vehicle and, finally, in the area of systems integration, makes certain that the approximately one million parts provided by hundreds of firms for the combined vehicle all fit and work together.

Gemini Two Man Orbital Program

The two-man Gemini program was an invaluable bridge between Mercury, the nation's first man in space program, and the Apollo moon project. This intermediate program gave the space program its first practical experience in such key areas as:

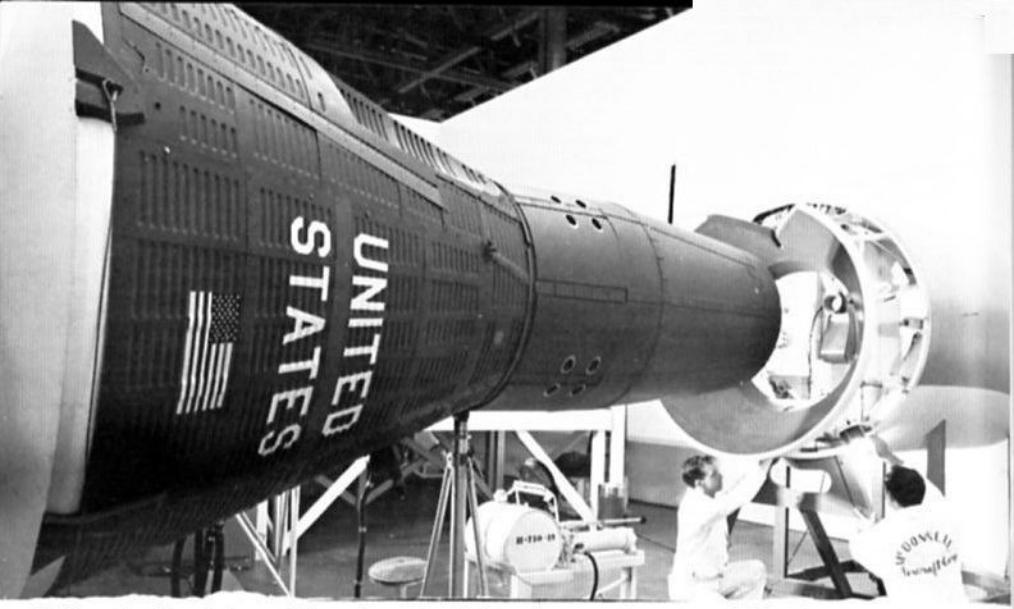
- Maneuvering in space.
- Rendezvous and docking with another space vehicle.
- Space walks, or extra-vehicular activity (EVA), as these strolls outside the spacecraft were called.
- Long duration flight.
- Pin-point landings.

The program, named after the third constellation of the zodiac (the twin stars Castor and Pollux), was started in late 1961, when it became apparent to NASA that it would have to learn more about manned space flight if man was to fly safely to the moon by the end of the 1960s.

The space agency decided to conduct 12 Gemini flights, the first two unmanned and the remainder with crews, to lay down these foundations for Apollo:

Goals of Gemini Program

- Determine how both men and equipment reacted to what was then regarded as a long time in space — two weeks. The first few trips to the moon will take about eight to 10 days, including the return to earth; NASA had to know if man could take weightlessness and the other stresses of space flight for that time period. It was also important to see how earth-built equipment worked in the radiation, temperature and vacuum conditions of outer space; this information would have a con-



Full-scale Gemini model and part of the Agena stage to which the two-man capsule is mated in space, are checked for alignment.

siderable bearing on the design of the later Apollo spacecraft.

- Prove that a manned capsule could find another space vehicle in the vast corridors of space (rendezvous) and then, having found it and maneuvered close to it, physically link up with the other vehicle (docking). Once in orbit around the moon, the Apollo spacecraft splits into two separate manned vehicles — the command-service module, which remains in lunar orbit, and the lunar module, which drops down to the crater-pocked surface. When the crew is ready to leave the moon, they must fly the lunar module up into orbit, find the mother ship, maneuver to it and join it.
- Acquire a large amount of data on the physiological and psychological stresses that man is likely to encounter in space.
- Show that a manned spacecraft can make accurate re-entries from space and bulls-eye landings close to the planned areas where recovery forces await the astronauts. Apollo has very little margin for error as it streaks back toward earth at the end of the flight; it has to pass through a 40-by-300-mi. frame (see above) to make a safe landing.

Achievements of Gemini Program

The Gemini program more than met all of these objectives. In less than two years of flight operations, ten two-man crews flew high and wide through space. They conducted experiments that added significant new knowledge to the fields of astronomy, meteorology, geology, medicine, biology and engineering. They proved that the flight maneuvers that Apollo would later need, could be done. Finally, they honed their already razor-sharp piloting abilities for future space flights, for the odds are better than even that at least two of the three astronauts who will land on the moon someday will be Gemini veterans.

Unmanned Start

After several years of manufacturing and ground-testing, the flight phase of the Gemini program got started Apr. 8, 1964, when an unmanned version of the two-seater spacecraft was boosted from Complex 19 by a modified Titan 2 rocket. Called "GT-1" for Gemini-Titan One, the flight was primarily a test of the spacecraft-rocket combination, to see if the two held together during the critical high-speed climb into space. The empty Gemini, still attached to the second stage of the Titan-2, was placed in orbit with a perigee (low point) of 87-mi. and an apogee (high point) of 173-mi. No attempt was made to recover the vehicle, for the test was finished after orbit was achieved, and the combination later burned up when it re-entered the earth's atmosphere.

Heat Shield Test Successful

The GT-2 mission also was unmanned.

It was flown Jan. 19, 1965, to prove that the spacecraft's heat shield would stand up under the heat loads of re-entry and to demonstrate that the many electronic systems inside the capsule worked as they were supposed to.

This second Gemini mission was an up-and-down flight that lasted only 18 min. and ended 1,850-mi. downrange from the Cape. Its success cleared the way for astronauts, who had been impatiently standing by since the Mercury program had ended almost two years before, to scramble into the next Gemini.

First Manned Gemini

The honor of being the first Gemini crewmen went to the late Virgil I. ("Gus") Grissom and John W. Young. Grissom, then an Air Force Major, had been the pilot of the second sub-orbital Mercury flight, "Liberty Bell-7" in the summer 1961. Shortly after that earlier space mission had ended with a great splash some 300 mi. downrange of the Cape, Grissom's "Liberty Bell" capsule sank and he had a close brush with drowning. Determined that this would never happen to him again, Grissom unofficially nicknamed his Gemini craft the "Molly Brown," after a Broadway play—"The Unsinkable Molly Brown"—then popular.

Corned Beef In Space

Young, then a Navy Lieut. Commander, made his first space flight on the Gemini-Titan 3 (GT-3) mission. It was the boyish-looking Young who smuggled a corned-beef sandwich aboard the "Molly Brown" and nonchalantly handed it to Grissom during the flight when the latter — expecting freeze-dried, cubed space food — asked for something to eat.

The GT-3 got underway at 9:24 a.m., EST, Mar. 23, 1965. The flight lasted only for three orbits — 4 hr., 52 min., 31 sec. — but in that short time, Command Pilot Grissom and Pilot Young managed to prove the space worthiness of the new craft.

First Controlled Space Flight

During their first orbit, Grissom grasped the small control stick on his left side and caused a series of small rocket motors on the spacecraft to fire. For the first time in the space age, a manned spacecraft changed its orbital path. The process was repeated during the second orbit.

Perigee during the flight was 87.5 naut. mi. and the apogee was 121 naut. mi. The Molly Brown fired its retrorockets, which reduce a satellite's speed below that needed for orbital flight, shortly before 2:00 p.m., EST, that afternoon and Grissom and Young began the long, shallow glide back to earth. They landed about 50-mi. uprange of the planned landing area, but by 3:30 p.m., both men were safely inside a Navy helicopter from the carrier, USS Intrepid.

Five Scientist-Astronauts whose selection was announced by the National Aeronautics and Space Administration on June 29, 1965. Front row, left to right, are F. Curtis Michel (physicist); Harrison H. Schmitt (astrogeologist); and Joseph P. Kerwin (physician). Back row, left to right, are Owen K. Garriott (physicist); and Edward G. Gibson (physicist).

Although most people expected that the space agency would name one veteran Mercury astronaut and one rookie to each of the first several Gemini missions, NASA surprised everyone by naming two men who had never flown before in space to be the Gemini-Titan 4 (GT-4) crew. Command pilot was James A. McDivitt and pilot was the late Edward H. White, 2nd. Both were then Air Force Majors and it was said that NASA regarded these two young men as two of the very best astronauts on its lists.

Four Day GT-4 Flight

Their objectives were to prove that they and their spacecraft could function in space for four days, to show that man could live and work outside his spacecraft, and to conduct a number of experiments.

The GT-4 vehicle got off to a flying start at 10:16 a.m., EST, June 3, 1965. Immediately after getting into orbit, McDivitt took control of the spacecraft and tried to fly formation with the spent second stage of the Titan-2 that had boosted him and White into space. The effort was not very successful and McDivitt soon abandoned further pursuit of the stage because of the amount of fuel he was using.

Spacewalk By White

During their next two revolutions around the earth, McDivitt and White prepared the latter for his walk in space. After carefully readying all the equipment — including a gold-covered visor on White's helmet to prevent the sun from blinding him — Ed White opened his hatch and stood up on his seat.

Using a compressed gas gun, White fired the device to fly himself out of the GT-4 cabin and into cold, bright space. A line, part tether and part umbilical, prevented him from floating free of the spacecraft and at the same time provided precious oxygen to breathe.

World Nervous — Astronauts Casual

While the world listened nervously to the events taking place more than one hundred miles above the surface of the earth, the two GT-4 astronauts were casually — even humorously — going about their business. When White brushed his glove against McDivitt's window, the command pilot called out: "Hey! You smeared my windshield, you dirty dog!" And at the end of the 20-min. long spacewalk, White jokingly pretended to refuse to come back inside the capsule.

The two GT-4 astronauts completed 62 revolutions (which, because of the earth's rotation, are slightly longer than orbits) before returning to earth. They remained aloft for 97 hrs., 56 min., 12 sec. and landed about 56-mi. uprange of their recovery carrier, the USS Wasp. The lowest point McDivitt and White came to earth was 86.1 naut. mi.; the farthest they ventured above the surface of the earth was 159.9 naut. mi.

Gemini-Titan 5 Mission

The Gemini-Titan-5 (GT-5) mission was an extension of the preceding flight; it was meant to extend man's operating time in space by 100% — to eight days — while still not biting off more than crews perhaps could chew. The crew for this mission was Command Pilot L. Gordon Cooper, Air Force Lieut. Colonel and veteran of the last Mercury mission, and Pilot Charles ("Pete") Conrad, a Navy Lieut. Commander and Princeton graduate.

Pressure Problems

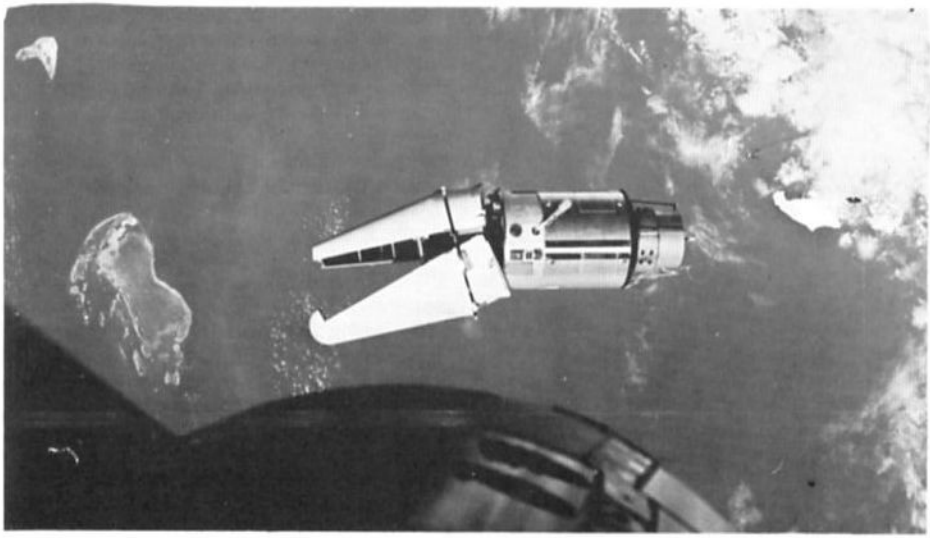
Cooper and Conrad soared into space Aug. 21, 1965, but within the first few hours a rapid pressure drop in the cryogenic propellant tanks for the spacecraft's fuel cells — the capsule's electrical power generating system — threatened to end the flight before it really began.

The GT-5 crew were unable to carry out the exercises they planned with the REP (Radar Evaluation Pod), a small package of electronics carried piggyback into space in the back end of the Gemini-5 spacecraft, because of the fuel cell problem. But later, when ground controllers determined that the fuel cell problem was not critical, Cooper and Conrad practiced rendezvous with a "phantom Agena" stage, just to gather experience in making precise maneuvers in space.

During the 190 hr., 55 min., 14 sec. long flight, the GT-5 crew reached apogees as high as 189 naut. mi. and perigee of 87.4 naut. mi. A ground computational error caused the two astronauts to land slightly more than 100-mi. wide of the mark when they returned to earth Aug. 29.

No Go For GT-6
Agena Failure Scrubs GT-6

The Gemini-Titan-6 (GT-6) mission found veteran Mercury astronaut Walter M. ("Wally") Schirra, a Navy Captain, and Air Force Lieut. Colonel Thomas P. Stafford, making his first flight, inside the two-seat cockpit. These two astronauts were to have flown the first full rendezvous and docking mission with an Agena



Now famous "Angry Alligator", the Augmented Target Docking Adapter as photographed from the Gemini IX Spacecraft during one of their three rendezvous in space.

target stage Oct. 25, 1965, but the Agena blew up at the instant it was to have driven itself into orbit and so the mission had to be cancelled.

Twin Launch

The space agency soon showed it was capable of bouncing back from adversity, for within days after the Gemini-6 Agena's failure, NASA announced that it had combined the GT-6 and GT-7 flights into one mission. It was informally called "Gemini 76."

After Gemini-Titan-7 (GT-7) was in orbit, the space agency said, it would rapidly re-install the GT-6 vehicle — now referred to as GT-6A — on the same pad and launch it so that it could rendezvous with its sister spaceship.

Schirra's and Stafford's Gemini-Titan-6 vehicle was removed from Complex 19 and the GT-7 vehicle of Frank Borman and James A. Lovell, Jr., was erected in its stead. Borman, an Air Force Lieut. Colonel, and Lovell, a Navy Commander, made their first space flight on GT-7.

On Dec. 4, 1965, the GT-7 vehicle lifted off Complex 19 in what was to be the longest flight in the Gemini program and the U.S. manned space flight program until then. Within minutes after it had cleared the pad, ground crews rushed in to prepare Complex 19 for the resurrection of the GT-6 booster and capsule.

Problems Beset GT-6

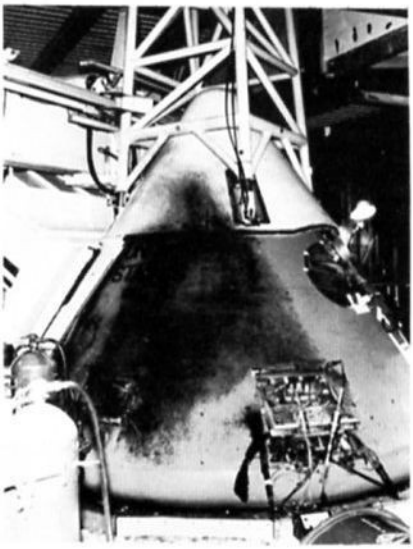
By Dec. 12, the eighth day that Borman and Lovell were in orbit, the GT-6 vehicle had been readied once again for flight. The countdown proceeded smoothly and the twin engines in the first stage of the Titan-2 roared to life exactly on the second calculated for Schirra and Stafford to fly upward and join Borman and Lovell.

But lift-off of the GT-6 vehicle didn't happen. An electrical tail plug came out too early and caused Schirra's and Stafford's mighty booster to shut down 1.2 sec. after ignition. There was no way for either Command Pilot Schirra or Pilot Stafford to know exactly what had happened, but both men cooly assessed the situation to be non-hazardous and decided against firing their ejection seats. Their calm, split-second analysis of the situation saved the vehicle for another launch attempt.

Later, ground crews found a small plastic "dust cover" in one of the lines leading to the first-stage engines. Had the tail plug not fallen out prematurely, the Dec. 12 launch would have been aborted by the dust cap.

Successful Liftoff

NASA, Air Force and contractor personnel worked feverishly to recycle the GT-6 once more. Three days later, on Dec. 15, as Borman and Lovell were in



The day after the Jan. 27 fire that killed astronauts Grissom, White and Chaffee—the outside of their fatal spacecraft is charred and blackened by flames which erupted from inside the capsule during the peak of the inferno.

their eleventh day in space, Schirra and Stafford tried again to get themselves into orbit. This time they were successful.

Several hours after lift-off, Schirra and Stafford drew within 100 ft. of the Gemini-7 spacecraft and Stafford calmly told the ground: "One-hundred-twenty feet and sitting." Back down on the ground, in the Mission Control Center at the space agency's Manned Spacecraft Center in Houston, Tex., mission controllers suddenly broke out small American flags and placed them on top of their consoles. The Gemini-6 crew had just made the world's first rendezvous in space.

Rendezvous In Space

The two manned spacecraft hovered side by side for almost five hours that day, coming within 1 ft. of each other. They photographed each other's spacecraft, cracked jokes about the Army-Navy football game (Borman, a West Point graduate, was badly outnumbered by Lovell, Schirra and Stafford, who were all Annapolis graduates), and took turns maneuvering around each other. Finally, Schirra pulled the Gemini-6 capsule away from Borman and Lovell and both crews settled down for some much-needed rest.

Jingle Bells

On Dec. 16, 1965, several hours before he and Tom Stafford were scheduled to fire their spacecraft's retrorockets, Schirra radioed down to the ground: "This is Gemini Six. We have an object, looks like a satellite, going from north to south, up in a polar orbit. He's in a very low trajectory . . . looks like he may be going to reenter pretty soon. Stand by . . . it looks like he's trying to signal us." This report was immediately followed by a rendition of Jingle Bells," with Schirra playing a small harmonica and Stafford accompanyig him with a small set of bells.

Schirra and Stafford were in orbit for 26 hr., 1 min., 40 sec. In that time, they flew as high (apogee) as 168.1 naut. mi. and as low (perigee) as 86.9 naut. mi. In all, they made 16 revolutions of the earth before they landed Dec. 16 less than 10 mi. from the carrier, the USS Wasp.

Longest Manned Flight

Meanwhile, Borman and Lovell continued to ride the skies. These two men returned to earth, bearded and tired, but in surprisingly excellent physical shape, early in the morning of Dec. 18, 1965. They landed within 8 mi. of the Wasp and were quickly picked up. Borman and Lovell had been in space for 330 hr., 35 min., 31 sec. — the longest any manned spacecraft had been in space until then, American or Russian.

Neil A. Armstrong and David R. Scott, command pilot and pilot, respectively, were picked as the crew for the eighth Gemini mission, Gemini-Titan-8 (GT-8). Armstrong, although a former naval aviator, was the first civilian to fly in space; Scott was then an Air Force Major, like Borman, Schirra and others, assigned by the Defense Dept. to NASA.

GT-8 Liftoff

The GT-8 mission began smoothly enough Mar. 16, 1966, when the Atlas-Agena target vehicle leaped off its pad here at Cape Kennedy. Engineers anxiously watched their telemetry data to see if the fixes made to the Agena, as a result of its failure in the Gemini-6 mission the previous autumn, were satisfactory. Both the Atlas and the Agena worked like charms and the Agena took up a circular orbit 161 naut. mi. above the earth's surface.

Exactly 101 min. later, as the Agena completed its first pass around the world and came speeding back over Cape Kennedy, Armstrong and Scott were launched. Their Titan-2 booster pushed

them into an initial orbit with a perigee of 87 naut. mi. and an apogee of 146 naut. mi. The two astronauts were racing on a track much smaller than, and inside, that of the Agena; the complicated geometry and mathematics of rendezvous state that the vehicle flying the smaller course will eventually catch up with the vehicle moving in the larger circle.

When the Gemini-8 astronauts vaulted into space, their Agena was a little more than 1,000 mi. ahead of them. Relentlessly, they pursued it until, some six hours after launch, Armstrong fired his spacecraft's thrusters to add the final bit of velocity that brought the capsule snugly along side the Agena.

Space Docking Accomplished

And then the Gemini-8 command pilot scored another space first for the U.S.: he deftly plugged the nose of his Gemini into the matching receptacle on the forward end of the Agena. It was the first docking of two space vehicles.

There were plans to fire up the Agena's propulsion system and drive the two connected vehicles around the sky; Scott also was scheduled to take a space walk. But a short-circuit changed all that.

Demonstration Model of the Apollo Applications Cluster Configuration photographed at Manned Spacecraft Center in Houston, Texas.

Short Circuit Causes Emergency Landing

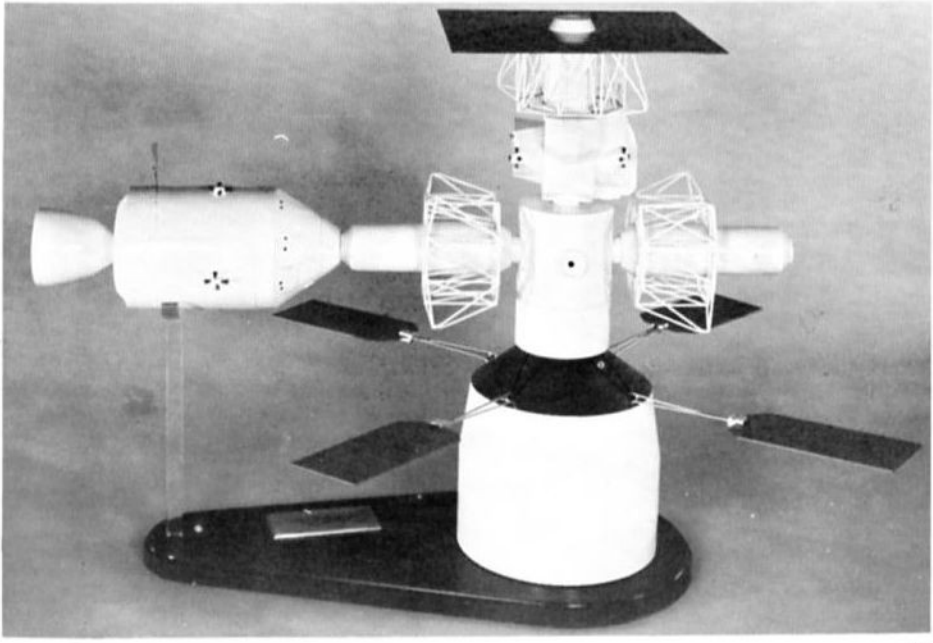
Less than 30 min. after Armstrong had joined up with the Agena, the combined space vehicle began to buck and toss. When the rolling and turning grew worse, Armstrong disconnected from the Agena and backed away. The problem proved to be a short-circuit on one of the small rocket engines on the back end of the Gemini-8 spacecraft; the short was causing the engine to fire almost continuously.

The two astronauts had to use another rocket engine system, normally not brought into play until the spacecraft has begun its descent back to earth, to stop the wild oscillations. Concerned for their safety, ground controllers ordered Armstrong and Scott to prepare for an emergency landing.

Splashdown In Pacific

After seven revolutions of the earth and only 10 hr., 41 min., 26 sec., Armstrong and Scott splashed down in the western Pacific Ocean, slightly more than 1 mi. from the calculated impact point. The area was about 500 mi. east of Okinawa and slightly more than 600 mi. south of Yokosuka, Japan.

The GT-8 spacecraft hit the water at 10:22 p.m., EST (but it was broad daylight in the western Pacific at this time; it was for this reason that the astronauts



The third class of astronauts, announced by NASA October 18, 1963 are (seated, left to right): Edwin E. Aldrin, Jr., William A. Ander, the late Charles A. Bassett II, Alan L. Bean, Eugene A. Cernan, and the late Roger B. Chaffee. Standing (left to right) are Michael Collin, R. Walter Cunningham, Donn F. Eisele, the late Theodore C. Freeman, Richard F. Gordon, Jr., Russell L. Schweickart, David R. Scott, and Clifton C. Williams, Jr.

were told to land there), and USAF Pararescuemen parachuted into the water alongside the disappointed crew within minutes. The Pararescuemen kept the astronauts company for 3 hr. while a Navy destroyer, the USS Mason, steamed to the scene.

Atlas Explodes

On May 17, 1966, Tom Stafford was seated in the Command Pilot seat of the Gemini-Titan-9 (GT-9) spacecraft while Eugene A. Cernan, a Navy Lieut. Commander, held down the Pilot's right-hand seat. They were prepared to chase down and lasso another Agena in space, but the Atlas that was propelling the target stage into space exploded and both vehicles fell into the Atlantic Ocean off Cape Kennedy.

NASA and Air Force quickly rounded up another Atlas and, because there was not a spare Agena in the Gemini program, put together a makeshift spacecraft called the Augmented Target Docking Adapter (ATDA). The ATDA carried the rendezvous and docking systems of the Agena for which it was pinch-hitting, but it lacked the Agena's muscular propulsion system.

Difficulties Delay GT-9

On June 1, 1966, the Atlas worked perfectly and placed the 12-ft. long, 1,700-lb. ATDA into a circular 161 naut. mi. orbit. Just about 100 min. later, as Stafford and Cernan were preparing for their launch, difficulties developed in a ground-based system and their launch had to be postponed. For Stafford, it was the fourth time that he had climbed into a Gemini cockpit, only to climb back out again, ride the elevator back down to the ground and wait for another re-scheduled launch date. His fellow astronauts needled him by saying that he had acquired almost as much time in the elevator that runs up to the Gemini spacecraft level as he had hours of space flight.

The Angry Alligator

But on June 3, Stafford and Cernan finally made it into space. Once there, they found that the two-piece protective nose cone on the forward end of the ATDA had split, but had not fallen away from the target vehicle as it should have. Stafford said the still-attached shroud made the ATDA look like "an angry alligator." Because of the cover, Stafford and Cernan were unable to practice docking with the ATDA.

But Cernan spent almost 2 hr. walking in space June 4. He literally worked up quite a sweat trying to do the many things planned for him during extravehicular activity (EVA) and the inside of his helmet became so badly fogged that he was no longer able to see out. Stafford finally told his partner to return to the spacecraft. He had been outside for about 127 min.

Stafford and Cernan landed their Gemini-9 spacecraft in the morning of June 6, 1966, after having spent 72 hr., 21 min. in space. Their highest apogee had been 168.2 naut. mi., their perigee 85.7 naut. mi. and their landing — less than a half-mile off the target point — was the most accurate splash made in the program.

John W. Young, who had been Gus Grissom's partner in the inaugular flight of the Gemini program, and Michael Collins, a rookie, were the space helmsmen for the Gemini-Titan-10 (GT-10) mission.

In the first afternoon launch of the Gemini program, the Atlas-Agena roared out of sight at 3:39 p.m., EST, July 18, 1966. Young and Collins followed at 5:20 p.m., EST, from their pad, a little more than 1 mi. north of the Atlas-Agena complex.

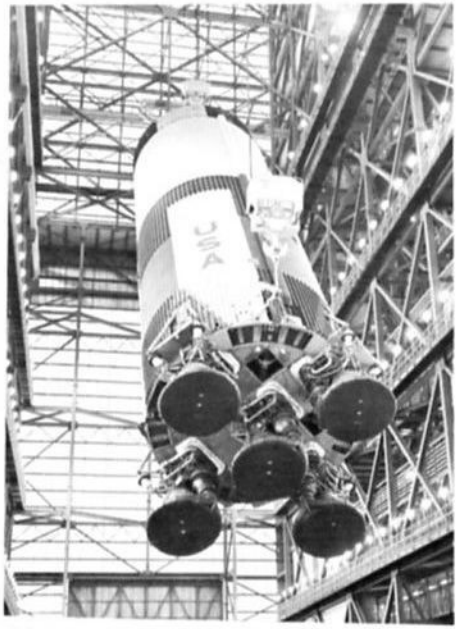
Successful Agena Rendezvous

The Gemini-10 crewmen caught up with their target vehicle later that same night and joined the two spacecraft together. They used the Agena's big engine three times to raise their altitude to 412.2 naut. mi. — then a world record — and finally circularize it about 200 naut. mi.

Later, Young and Collins left the Gemini-10 Agena and shot a rendezvous with the Gemini-8 Agena of Armstrong and Scott. The Gemini-8 Agena had been left deliberately in a high orbit so that future crews might practice additional rendezvous exercises with it.

Two EVA's For Collins

Collins also performed two EVAs. The first was conducted while the pilot stood up in his seat. "It's almost like standing with your head up through the roof of a car going sideways across the world," Collins described it. But after 50 min. of this stand-up EVA, as he was taking photographs and conducting other experiments, something got into the two astronauts breathing loops and irritated their eyes. Collins was forced to sit down and close the hatch over his seat.



Unfueled first stage (S-1C stage) for NASA's Apollo/Saturn 502 space vehicle is shown being hoisted into High Bay No. 2 of the Vehicle Assembly Building at John F. Kennedy Space Center.

Later, with the difficulty cleared up, Collins again opened his hatch and this time left the spacecraft. This space walk lasted 39 min. and Collins managed to retrieve an experiment that had been attached to the Gemini-8 Agena since the previous March. The crew carried the micrometeoroid experiment back to earth with them.

Young and Collins came down July 21, 1966, after having been in space for 70 hr., 46 min., 39 sec. They hit within 3½ mi. of the planned landing point and were quickly fished out of the water by the USS Guadalcanal.

Tough Assignment For GT-11

Gemini-Titan-11 (GT-11) crewmen Charles ("Pete") Conrad and Richard F. Gordon faced a tough assignment: where their fellow astronauts had had up to 5 hr. in which to chase and catch an Agena, they had to do it in less than 90 min. Conrad, who had been the pilot of the Gemini-5 mission, considered it an exciting challenge, as did Gordon, a Navy. Lieut. Commander making his first space flight.

First-Orbit Rendezvous

A first-orbit rendezvous was achieved by launching the Gemini spacecraft before the Agena target stage completed its first revolution of the earth and, zooming over Cape Kennedy, got too far ahead of Conrad and Gordon.

Where other crews had not been launched until the Agena was more or less over the Cape, the Gemini-11 astronauts left Complex 19 on Sept. 12, 1966, while the Agena was hurtling over Texas, Louisiana, and the Gulf of Mexico. In the several minutes it took the Titan-2 rocket to lift the Gemini-11 spacecraft into orbit, the Agena continued to move across the skies so that both wound up in the same general vicinity of space at about the same time

Conrad used the spacecraft's rocket thrusters to make a series of maneuvers during the first 50 min. he and Gordon were in space. These firings closed the gap, already small to begin with, between themselves and their target stage. Finally, 78 min. after they had been launched, Conrad and Gordon were floating alongside their Agena and a first-orbit rendezvous — similar to a situation that an Apollo spacecraft could possibly face someday — was successful.

Dick Gordon then tried his hand at space-walking and found it was no easy task. About 24 hr. after launch, the Gemini-11 pilot opened his hatch and floated outside the spacecraft. He set up a camera to record his activities, retrieved an experiment from the Agena, and attached a long nylon strap between the nose of the Gemini and the forward end of the Agena.

This latter activity, intended for an experiment scheduled later in the flight, proved to be extremely difficult and tiring. The astronaut was panting with fatigue and Command Pilot Conrad ordered him to return to the cockpit for rest. Gordon had been outside for about one-half hour.

New World's Record

Toward the end of their second day in space, Conrad fired up the 16,000-lb. thrust primary engine of the Agena and rocketed himself and Gordon to a new world's altitude record: 741.5 naut. mi. above the surface of the earth. "We just had the impression that we were looking down at the ground, going straight up," Conrad said later of the experience. The crew stayed in this lofty orbit for two more revolutions "and we saw some of the most amazing sights that man has ever seen," as Conrad later described the view of earth from that altitude.

The Agena's big engine was fired again, several hours later, but this time as a power-brake, instead of an accelerator, and Gemini-11 dropped down to a 156-164 naut. mi. orbit. At that lower altitude, Gordon conducted his second extra-vehicular activity but this time he only stood on his seat, with his hatch open. For slightly more than two hours, he conducted photograph experiments.

Connected By Line

During their third day in orbit, Conrad disconnected his spacecraft from the Agena and backed off to the length of the nylon strap Gordon had attached earlier to the two vehicles. The object of this experiment was to determine if two objects, connected by a line, could stabilize each other in space through the differential gravity forces pulling on them. The results indicated that the idea was feasible.

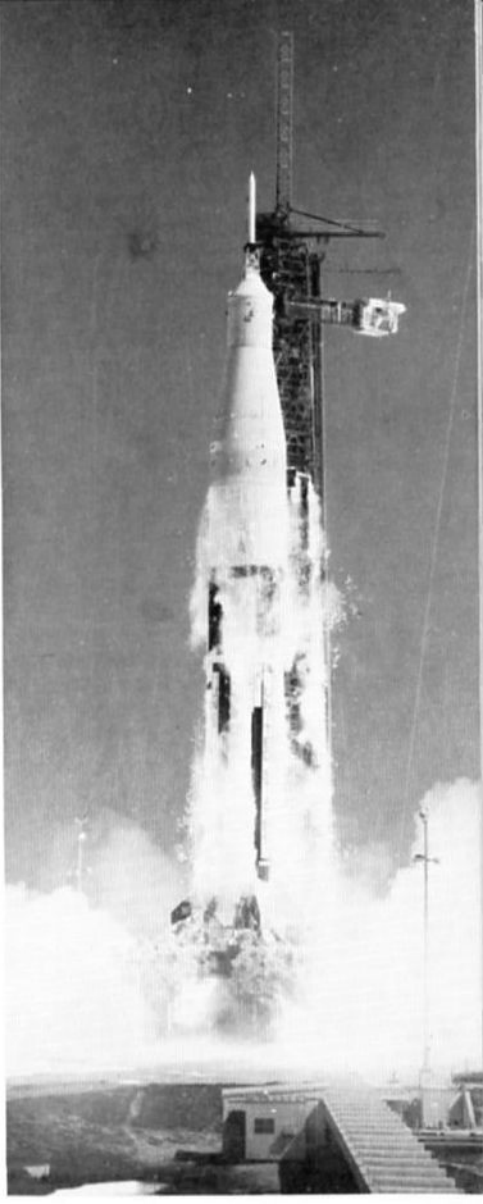
Conrad and Gordon landed Sept. 15, 1966, after having spent 71 hr., 17 min., 08 sec. in space. Their spacecraft splashed within 1.5-mi. of the recovery carrier, the USS Guam. The re-entry and landing was automatically controlled by the spacecraft's guidance system and computer, with Conrad and Gordon maintaining "hands-off" during the dive back to earth.

End Of Gemini

On Nov. 11, 1966, two white-suited astronauts — James A. Lovell, Jr. and Edwin E. Aldrin, Jr. — walked up the ramp to the elevator of Complex 19. The first one had a hand-lettered sign on his back reading "THE" and the second had a similar sign but reading "END." It was their joking way of saying that their mission, Gemini-Titan-12 (GT-12), was the end of the line for the two-man program.

Lovell, who had been the pilot of the marathon Gemini-7 flight, was the Command Pilot for this last flight. Aldrin, an Air Force Major with the nickname of "Buzz," was making his first flight. Because of the difficulties earlier astronauts Cernan, Collins, and Gordon had encountered space-walking, Gemini-12 — and Aldrin — carried as one of its major goals the objective of finding out as much as posible about the difficulties of working in space.

Rendezvous and docking with their Agena proved easy, but the possibility of a rough Agena engine led ground controllers to cancel plans for Lovell and Aldrin to fire up the stage and climb more than 400 naut. mi. out in space.



Apollo-Saturn 201, the first of the S-1-B series, lifts off from Pad 34 at Cape Kennedy on February 26, 1966.

Nineteen new astronauts announced by the National Aeronautics and Space Administration, April 4, 1966, (seated, left to right) are: Edward G. Givens Jr., Edgar D. Mitchell, Charles M. Duke Jr., Don L. Lind, Fred W. Haise Jr., Joe H. Engle, Vance D. Brand, John S. Bull, and Bruce McCandless II. Standing (left to right) are: John L. Swigert Jr., William R. Pogue, Ronald E. Evans, Paul J. Weitz, James B. Irwin, Gerald P. Carr, Stuart A. Roosa, Alfred M. Worden, Thomas K. Mattingly, and Jack R. Lousma.

EVA Work Assignments

During the second day in orbit, Buzz Aldrin slipped out of the spacecraft and, using a series of portable hand-holds and hand-rails, moved himself to the back end of the Gemini. There, a work station — with a series of tasks, such as cutting a dummy wire bundle, connecting and disconnecting several electrical plugs, etc. — awaited him.

The astronaut also worked on a smaller experiment on the Agena, using tools to tighten and loosen specially-instrumented bolts. Aldrin later reported that it was possible to work in space provided that the man was firmly anchored to the work station by body harness straps and/or foot restraints. All totalled, Aldrin performed three EVAs — two standing up on his seat and the third completely outside the spacecraft.

Gravity-Gradient Experiment

The Gemini-12 crew also performed a tethered gravity-gradient stabilization experiment, as Gemini-11 had done, and the results were corroborating.

Despite a number of nagging equipment problems with their spacecraft, Lovell and Aldrin managed to get through their four-day mission as planned. They spent 94 hr., 34 min., 31 sec. in space before landing 3.8-mi. from the recovery carrier, USS Wasp, in the afternoon of Nov. 15, 1966.

Gemini Spacecraft Details

The Gemini spacecraft was a versatile machine built by the McDonnell Aircraft Corp. It was built in segments — called "modules" by engineers — and each segment had a specific purpose:

● **Rendezvous and Recovery** This was the nose section of the Gemini; it housed the radar which tracked down Agenas in the skies as well as the parachute system that lowered the spacecraft gently to the water at the end of flight.

● **Reaction Control System**. In this drum-shaped section, just forward of the crew compartment, were two rings of small (25-lb. thrust) rocket engines. These little motors were used only during re-entry to stabilize the spacecraft in its blazing descent back to earth.

● **Cabin** Here the two astronauts sat side-by-side in a pressurized cabin. An overhead hatch, with a triple-plane window, was above each man's seat. Facing the crewmen was an instrument panel with more than 100 dials and indicators. Each astronaut had a control handle that triggered the spacecraft's thrusters and drove the Gemini through space.

● **Adapter**. This two-piece module housed both the spacecraft's vital retrorockets and the systems required for flight through space. The four solid-propellant retrorockets were mounted in the retrograde section of the adapter, immediately behind the crew cabin. When these motors were fired, they cut enough forward velocity from the speeding spacecraft to prevent the capsule from remaining in orbit. The equipment section of the adapter was the bottom-most part of the 18½-ft. long, 10-ft. base dia., 7,100-to-8,400-lb. spacecraft; here was contained the rocket engines that enabled Gemini to go forward and back up, up and down, or sideways, and the rocket fuels that fed those engines. Here also were the electrical power system (fuel cells) and its propellants, breathing oxygen, etc. The external skin of the adapter also served as the spacecraft's radiator. When astronauts prepared to come down from space, they first jettisoned the equipment section of the adapter by firing an explosive charge. This kicked that segment away and freed the retrockets for their task. After the retrorockets were fired, this final section of the adapter also was kicked away to clear the heat shield of the crew module for re-entry.

The **Titan-2 Rocket** that provided safe, dependable taxi service for ten Gemini crews was a modified version of the two-stage war weapon. Air Force and the Martin Co., prime contractor for the rocket added these features to the Titan-2 for NASA:

● **Emergency Detection** system. Basic-

Gemini capsule

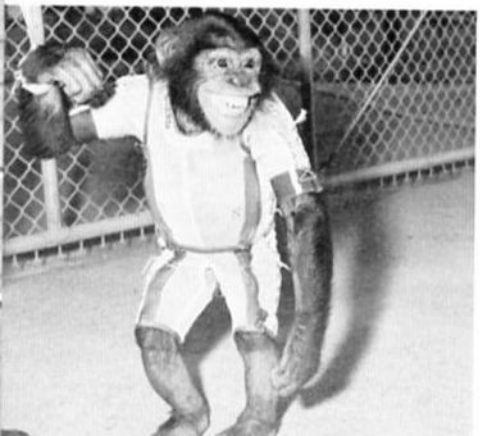
Astronaut Shepard steps from his capsule, aboard the recovery ship, after his sub-orbital space flight May 5, 1961.

ally a fire alarm system, this consisted of sensors located in crucial areas of the Titan-2 to warn astronauts of impending danger.

● **Backup** (spare) **Flight Control System** This was a second complete set of engine controls on the first-stage engines; it was comparable to the second set of brake lines now found on automobiles. If the first set fails, the second set immediately comes into play.

● **Backup Electrical System** The second power system guaranteed that the Gemini booster would have electrical power during powered flight, even if the primary system might fail.

● **Radio-Command Guidance** system. Built by GE and the Burroughs Corp., the radio guidance system of the Atlas replaced the all-inertial system originally used by the Titan-2 ICBM. The radio system was lighter in weight and had proven its reliability and accuracy in the Mercury program when NASA stipulated that it be used in Gemini.



The space traveler, Ham, in his mesh space suit.

Mercury

Project Mercury was the first step taken by the United States into space.

The project saw six American pilots fly into space (two of them on sub-orbital ballistic flights of 300 miles distance) and every one returned safely to earth with his mission accomplished. The flights proved that man could go into space for periods of time up to 34 hours and, while there, function as a pilot, as an engineer and as a scientific experimenter.

No one who is familiar with the na-

tional space program doubts for a second that Project Mercury laid the foundation for Projects Gemini and Apollo.

The newly-created civilian space agency formally took over the Mercury manned space flight project Oct. 7, 1958, from the Air Force, which had been studying the feasibility of the concept for about two years.

Its program had three major objectives: place a manned spacecraft in orbital flight around the world; determine man's abilities to perform tasks and function normally while in a space environment; and return the man and his spacecraft safely to earth.

Existing Technology Employed

To meet these objectives, NASA insisted that existing technology and available components be used as much as possible, that simplicity and reliability be made key factors in the design of the spacecraft, that the pilot be given the ability to control — under his own hand — the attitude of the spacecraft in space, that the spacecraft be of a ballistic shape and that it (the spacecraft) be equipped with a launch escape system and a retrorocket system — the former to pull the pilot and his craft away from a malfunctioning launch vehicle and the latter to insure his return from space.

The agency also insisted that an existing launch vehicle be used as the booster and that the landing be made in water.

Given this bracing set of requirements, the wonder is not that the agency was 22 months late in meeting its target date of a manned orbital flight, but that it was only 22 months late.

Mercury Manned Orbital Flights

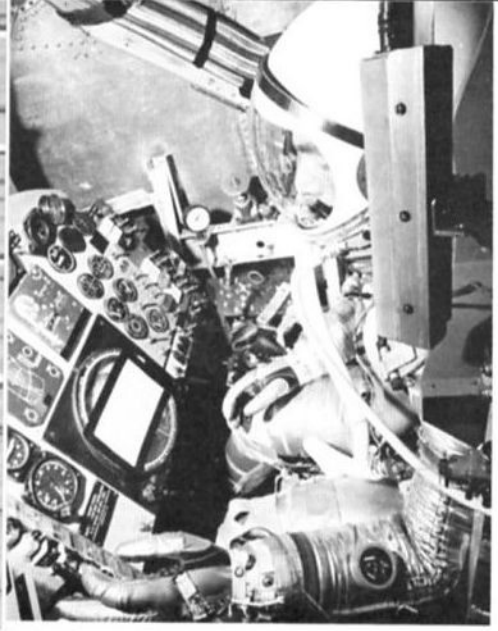
With the successful three-orbit flight of U.S. Marine Lt. Col. John H. Glenn on Feb. 20, 1962, NASA met the goals it had set for itself in 1958. But between 1958 and that day in early 1962, the progress that had been made in Project Mercury only whetted the appetite of the agency for more knowledge about man's role in space.

The Kennedy Administration backed NASA's plans and the project was extended.

The agency ascertained that Glenn's flight was not a random success when it sent Navy Lt. Cdr. M. Scott Carpenter on a similar three-orbit mission later that Spring. Although Carpenter's flight lacked the precision and tautness of Glenn's, he did complete his primary tasks and returned safely.

Encouraged by these two flights, NASA then made a quantum jump with the six-orbit flight of Navy Cdr. Walter M. Schirra later that year. Schirra's flight was described as "an engineering test flight" — meaning that he went aloft intent on seeing how much performance he could squeeze out of his vehicle and making evaluations of that performance.

Astronaut John Glenn, just prior to entering his capsule Feb. 20, 1962. The scene is the "white room" atop the Atlas gantry.



Astronaut Scott Carpenter examines the instrument panel of his capsule May 24, 1962.

Schirra also, as far as is known, made the first experiments in drifting flight, in which he made no attempt to maintain the attitude of his craft but let it float at random for several orbits.

NASA closed the Mercury book in the Spring of 1963 with the 34-hour flight of USAF Maj. L. Gordon Cooper. The pilot of the longest U.S. space flight up to then, Cooper showed no adverse affects for his experience. More than anything, however, Cooper demonstrated the advantages to be gained by adding man to a system — when his spacecraft short-circuited late in the flight.

Cooper managed to by-pass the faulty circuits and flew his craft manually — that is, under the direct and immediate supervision of his own hand — all the way down to a precise landing several thousand yards from the waiting aircraft carrier recovery ship.

Mercury Program Breakdown

All totalled, there were 25 flight-tests in the Mercury program and these might be grouped in three blocs:

• **Ten assorted tests** of the launch escape system and capsule heat shield, including eight flights aboard the solid-propellant Little Joe vehicle, one aboard an Atlas and one using the launch escape tower only.

• **Mercury-Redstone flights** were six in number and were designed to evaluate the performance of the Mercury capsule, measure the reactions of an astronaut to brief periods of space flights and to exercise the launch and recovery operations, during "ballistic lob"-type flights down the Atlantic range.

After three qualifying flights of the modified Army Redstone tactical missile and the Mercury capsule, one of which — MR-2 (for Mercury-Redstone mission #2) — successfully flew the chimpanzee "Ham" on a ballistic flight Jan. 31, 1961, the U.S. felt itself ready to commit a man to space flight.

Commander Shepard Is First

Navy Cdr. Alan B. Shepard, after a series of delays and postponements, finally launched his Freedom 7 capsule on a warm May 5, 1961. He rose to an altitude of about 115 miles and reached a peak speed of about 5,000 mph. on his arced flight path; the flight was a total success although it only lasted 15 minutes from lift-off to touch-down.

On July 21, Air Force Maj. Virgil I. ("Gus") Grissom made an identical flight, but his spacecraft was lost when it filled with water and sank to the bottom of the Atlantic.

• **Mercury-Atlas flights** were nine in number and the last four — MA-6 through MA-9 — were the manned orbital missions for which the whole program had been started.

MA-1 failed (July 29, 1960) in its attempt to subject a standard production-line Mercury capsule to a severe test of the spacecraft's heat-protection system. MA-2 finally achieved this and other objectives Feb. 21, 1961. MA-3, which was to have orbited an un-manned capsule around the world once and then recover it, failed when the Atlas booster malfunctioned and had to be destroyed.

MA-4 successfully carried out this goal Sept. 13, 1961, when it flew a "mechanical man" in an empty capsule once around the world and then safely recovered it. Finally, MA-5 on Nov. 29, 1961 made the last spacecraft qualification flight when it successfully flew the chimpanzee "Enos" in a one-orbit mission around the world.

There then followed the flights of Glenn (Feb. 20, 1962), Carpenter (May 24, 1962), Schirra (Oct. 3, 1962) and, finally, Cooper (May 15-16, 1963). With the exception of Carpenter's flight, which was meant to duplicate Glenn's, each

of these missions opened man's eyes to greater possibilities in space and provided a firm footing for his next step.

After Apollo What?

And what of the future? Man did not call it "quits" after Columbus had discovered the New World in 1492. If anything, that discovery led the way for others to come and see what they might find there. It was the searching of the unknown that led to the development of America; it may well be the search of the unknown in space that leads America to the discovery of new worlds in the universe.

Earth-Orbital Station

In late 1966 and early 1967, President Lyndon B. Johnson's administration and NASA decided to follow the Apollo manned lunar landing program with a project called Apollo Applications Program.

The Apollo Applications Program is designed to make maximum use of the launch vehicles and spacecraft built for the lunar landing mission in extending man's knowledge of earth, space and the planetary system. In announcing the follow-on program, NASA stated that it would have two principal objectives: To make unique contributions to practical applications, operational capabilities, science and technology; and, at the same time, to place the nation in a position to assess . . . the value and feasibility of future space flight and the interrelated roles of manned and unmanned systems."

The initial series of Apollo Applications flights will see a spent S-4B stage converted into an orbital workshop, once all of its propellants have been consumed. Apollo crews will crawl through an airlock connecting their spacecraft to the S-4B and work inside the latter's cavernous (and empty) liquid hydrogen tank, where a number of experiments will be located.

A key part of the Apollo Applications Program will be the Apollo Telescope

Helicopter picks up astronaut Alan B. Shepard after his brief flight into space while frogmen guard the craft against sinking. Below, sailors of the Navy destroyer Goa hoist Shepard's capsule from the ocean.

Three Americans in their Apollo spacecraft leave earth orbit and head for the moon (background). Below them is the Florida peninsula and Cape Kennedy from which they took off earlier.

The first Saturn/Apollo vehicle ever to be flown sits on the launch stand. This was an un-manned spacecraft.

Mount. In effect an orbiting manned observatory, the spacecraft will consist of the upper half of the Lunar Module. Attached to the bottom half of the Lunar Module's ascent stage will be a complex series of astronomical telescopes that will be used to study the sun during the peak of the sunspot cycle beginning in 1969.

Crew will remain in orbit, working inside the S-4B orbital workshop and the telescope mount, for periods of 28 days, then 56 days and eventually for 90 days or more. When these crews return to earth, other crews will fly up to the prototype space station to take their place.

The experience gained in the Apollo Applications Program is expected to lead to some form of permanent space station in the 1970s. The station would be manned at all times, with crews rotated periodically — say, every three months.

The Air Force has its own manned space program; it is called the Manned Orbiting Laboratory (MOL). The highly-secret MOL spacecraft consists of a cylinder, about 30 to 40 ft. long, 10 ft. in dia., and weighing about 25,000 lb.; there, two Defense Dept. astronauts will live and work for periods of at least 30 days. Attached to the front end of the MOL cylinder is a modified Gemini spacecraft; in that two-seater spacecraft, the MOL pilots will ride into, and back down from, space.

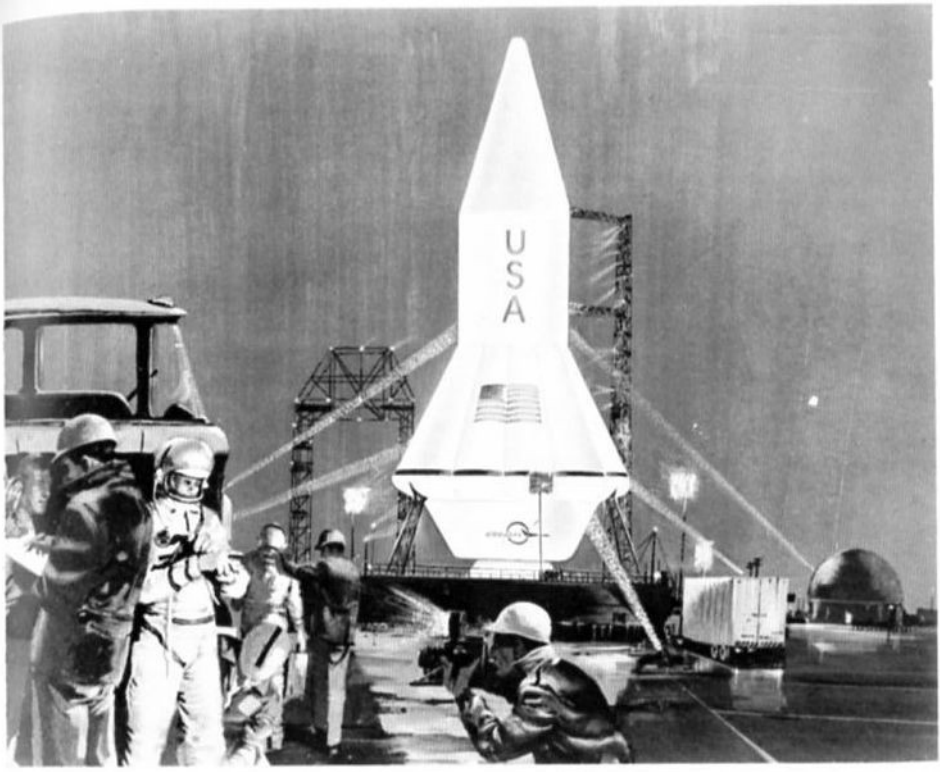
• **Weather watch and control center** where astro-meteorologists monitor and analyze the weather developments around the world.

Television cameras aboard the station look down on large areas of the world. Small, un-manned weather satellites — such as the Tiros spacecraft — operate at lower altitudes and transmit their pictures both to ground stations and the space station.

The close-up data provided by these auxiliary cameras then is interpreted in light of the broad patterns seen from the higher altitude of the station. Forecasts are prepared for the entire world, a hemisphere or a region.

• **Satellite maintenance and repair.** Using a small spacecraft designed to travel only through space, two or three highly-trained astro-repairmen leave the station and head for a satellite — perhaps a vital communications spacecraft — which has suddenly gone dead and stopped transmitting.

The crew discovers that a certain part has burned out. They replace it with



A concept of future launch vehicle; this one would be recovered and re-used after delivering its payload into space.

a spare and the satellite returns to life. Or, they find that a meteoroid has gouged a deep hole through the side of the satellite. In this case, on-the-spot repair becomes impractical and so they haul the damaged satellite back to the station where they can work on it in a well-equipped maintenance shop.

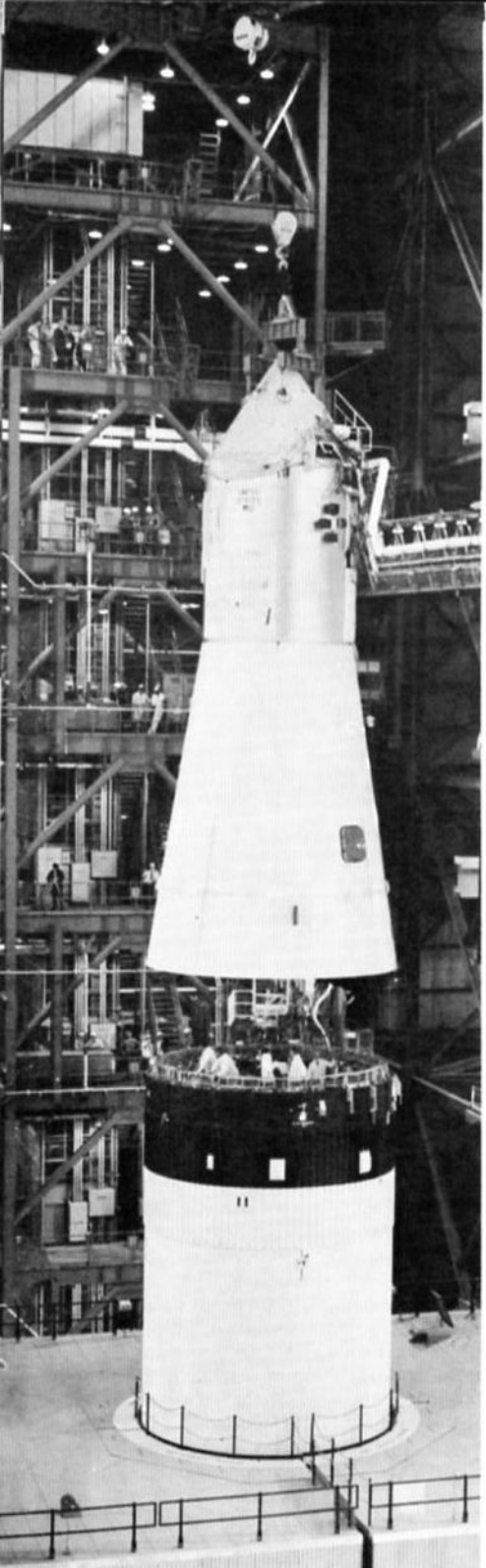
• **Space debris clean-up.** Although space is vast, it is getting cluttered with obsolete or dead satellites, which have long since finished their tasks in space but which nonetheless remain in orbit; the upper stages which propelled the satellites into orbit; adapter sections; insulation panels; etc. — like so much highway trash.

So that new satellites may fly upward through space without fear of colliding with a derelict stage, some way must be found to clean up the highways of space. The station crew members might find themselves assigned to clean-up details which will hunt down a dead satellite, attach a small solid-propellant motor to the carcass and then ignite it. The motor drives the debris down toward earth, where it slams into the atmosphere, breaks up and burns.

• **Navigation buoy and tracking station.** After several years in orbit, the crew can determine the position of their station to within inches of its actual place in space. Manned spacecraft flying into the far corners of space take accurate navigational fixes on the station; the station also uses its laser radar to track deep-space probes.

• **Way station and launch facility.** The station provides an excellent facility where expensive satellites may be checked out thoroughly before they are committed irrevocably to deep space; faulty parts may be replaced. Or, manned spacecraft seek refuge in the storm-cellar of the station during sudden solar radiation storms. Or, large space vehicles are assembled alongside the station so as to have access to tools, spare parts, electrical power and expert technical advice.

• **Scientific laboratory,** where almost



any type of scientific research is conducted—from space medicine to radio-astronomy. It need not be pure science; engineers might want to experiment with a new welding technique which requires the vacuum only space can provide.

What of the men who fly in space? They are, without exception, highly-trained, deeply-motivated and very courageous individuals. They are all, necessarily, pilots.

The original seven Mercury astronauts, chosen in 1959, were: M. Scott Carpenter, L. Gordon Cooper, John H. Glenn, the late Virgil I. ("Gus") Grissom, Walter M. Schirra, Alan B. Shepard, and Donald K. Slayton. Only Cooper and Schirra still remained on the active-flight list when Apollo missions began.

Second group of astronauts, picked in 1962, were: Neil A. Armstrong, Frank Borman, Charles ("Pete") Conrad, Jr., James A. Lovell, Jr., James A. McDivitt, the late Elliot M. See, Jr., Thomas P. Stafford, the late Edward H. White, 2nd, and John W. Young. See was killed, along with Charles A. Bassett, 2nd, in a Feb., 1966, plane crash in St. Louis, Mo.

The third group of astronauts, chosen in late 1963, included: Edwin A. Aldrin, Jr., William A. Anders, the late Charles A. Bassett, Alan L. Bean, Eugene A. Cernan, the late Roger B. Chaffee, Michael Collins, R. Walter Cunningham, Donn F. Eisele, the late Theodore Freeman, Richard F. Gordon, Jr., Russell L. Schweikart, David R. Scott, and Clifton C. Williams. Freeman was killed in a plane crash in Houston, Tex., in 1965.

The fourth group of astronauts, selected in early 1966, included: Vance D. Brand, John S. Bull, Gerald P. Carr, Charles M. Duke, Joe H. Engle, Ronald E. Evans, Edward G. Givens, Jr., Fred W. Haise, Jr., James B. Irwin, Don L. Lind, Jack R. Lousma, Thomas K. Mattingly, Bruce McCandless, 2nd, Edgar D. Mitchell, William R. Pogue, Stuart A. Roosa, John L. Swigert, Paul J. Weitz, and Alfred M. Worden.

In mid-1965, NASA announced the appointment of five scientists as astronauts: Edward G. Gibson (physicist), Owen K. Garriott (physicist), John P. Kerwin (Physician), F. Curtis Michel (physicist) and Harrison H. Schmitt (astrogeologist). These men were taught to fly by NASA so that they could, in future space missions, participate as full crew members.

Mating of Apollo Spacecraft.

Titan missiles fill the factory floor of the Martin Co. plant in Denver, Colo.

Space technology

A brief primer on all phases of space fundamentals

A close look at that imposing—and sometimes mysterious—structure known as "The Space Age," which has been constructed in the last few short years, will show that the building materials used have been the everyday bricks of physics, chemistry, electrical engineering and mathematics.

In this chapter, and in layman's terms, we shall examine some of the fundamentals and phenomena of space technology: structures, propulsion, guidance, communications (including all forms of electronic transmissions), power, reentry, and orbital mechanics. Since separate text-books could be written on each of these subjects (and, in fact, many have been written already), we shall explore them only to a depth that the average reader would find useful.

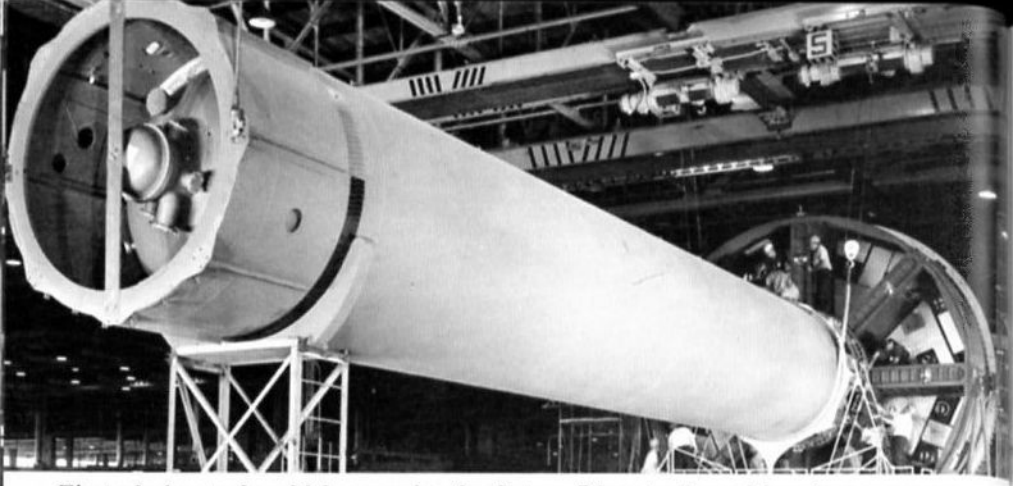
Rockets or Missiles?

The term "rocket," although avoided by most missile and space engineers because of its science-fiction and Buck Rogers connotation, is a generic one and describes any vehicle which contains within itself the means of self-propulsion.

Today, most engineers prefer to use "missile" to describe a military rocket and "launch vehicle" to describe a satellite-carrying rocket. But no matter what it is called, a rocket consists of an airframe (comparable to the fuselage of an airplane), propulsion system, guidance, and payload, or the package to be delivered into space.

All U.S. missiles and launch vehicles today are built so that their airframe and propellant tanks are integral. The same aluminum or steel cylinder which holds the propellants also is the mechanical structure through which the rocket engines transmit their thrust and impart velocities of 15,000 to 25,000 miles per hour (mph.) to the cylinder's payload of a satellite or nose cone.

Since part of the engines' thrust necessarily must be spent in pushing the weight of the airframe (as well as the engines themselves, the guidance system, power supplies, cabling, etc.), vehicle



First of nine tanks which comprise the Saturn I booster is positioned on a manufacturing jig at NASA's Saturn plant in New Orleans.

manufacturers always try to build the strongest structure for the lightest weight. Every pound saved on the launch vehicle means another few ounces for the payload.

Mass Ratio

The relationship between a rocket vehicle's empty weight and fully-fueled weight (the latter divided by the former) is called its "mass ratio." For example, the Douglas Aircraft Company's S-4 Saturn upper stage has a dry (empty) weight of about 13,000 pounds (lbs.) and a fully-fueled weight of about 114,000 lbs.—for a mass ratio of approximately 9-to1. The ideal rocket would have a mass ratio of infinity; everything—from airframe through power supplies—would be consumed in the engines and, finally, the engines themselves. Only the payload would be left.

Since the "ideal" rocket is impossible, vehicle manufacturers content themselves by striving for the highest possible ratios—20 or 25-to-1 is about the limit today.

The technique of "staging"—separating a rocket vehicle into two, three or four separate segments, or "stages"—is an attempt to improve the mass ratio of a given vehicle. As each stage uses up its propellants, or "burns out" to use the industry phrase, it is dropped from the speeding vehicle and the next stage is ignited. With the jettisoning of each successive stage, the dead weight of the rocket decreases and the velocity of the remaining stages and the payload increases (since each stage, at the moment of ignition, is already moving at the burn-out speed of the preceding stage).

Semi-Monocoque Structures

The major rocket manufacturers—the Chrysler Corp., Douglas, Martin Co., and North American Aviation, Inc.—usually build their missiles and launch vehicles as semi-monocoque structures.

This means a shell whose external skin is supported by an internal frame. A bird cage-like frame, consisting of vertical pieces called "stringers" or "stiffeners" (terms adopted from aircraft) and circular flat rings called "formers," is built first. Then the external skin—seldom thicker than ¼-inch (in.)—is welded to the frame to form a cylindrical segment called a "hoop."

Two or more hoops are welded together, depending on the size of the tank desired, and then elliptical-shaped domes are welded to the front and rear ends of the cylinder to form a complete tank. Two tanks—one for a fuel and the other for an oxidizer—then are joined by a coupling of the same diameter as themselves; it is called the inter-tank adapter.

There are variations on this basic theme. Some manufacturers begin the fabrication process with huge 2-in. thick slabs of aluminum alloy, which are shaped to form quarter-cylinders. Very heavy machinery (such as boring mills) then make cuts down to 1¾ in. deep and up to 8 in. wide in the starting stock.

When this trimming-out process is done—sometimes it takes as much as six weeks—a panel with integral skin and stiffeners, cut from one piece of metal, remains. Other companies use this technique to form an inter-stage adapter as an integral part of a tank, but avoid it

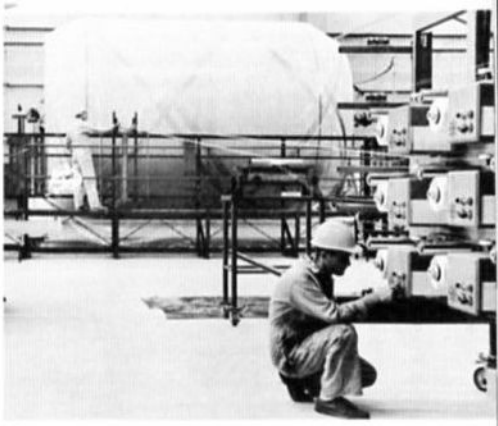
within the actual tankage volume itself. Instead, they either machine-mill or chemically-etch (the Martin Co. uses acid) the thickness of the starting stock down to the desired gauges in a waffle-like pattern. This manufacturing method considerably reduces the weight of the cylindrical airframe without compromising its strength.

Atlas and Centaur Unique

One company followed an entirely different path in building the Atlas missile and Centaur upper stage for the National Aeronautics and Space Administration. Both the Atlas and Centaur basically are stainless steel balloons—with skins only slightly thicker than ordinary kitchen foil-wrap—which are held up by a pressurizing gas inside. If the pressure should suddenly fail, the airframes of these vehicles would instantly wrinkle and collapse. Atlas has a mass ratio of approximately 30-to-1, the highest of all rocket vehicles in the U.S. inventory today.

Atlas and Centaur also have one other unique structural aspect—where all other missiles and launch vehicles have four tank domes (two—one top and one bottom—on each of two propellant tanks), Atlas and Centaur vehicles have only three.

To save weight on the Atlas, the company made one very long tank of approximately 75 feet (ft.) in length and, about 20 ft. up from the bottom dome, inserted the third dome, or bulkhead. This bulkhead serves simultaneously as the top dome of the fuel tank (the smaller of the two) and the bottom dome for the liquid oxygen tank. Approximately 160,000 lbs. of liquid oxygen (LOX) rests directly on this dome, but bulkhead reversal—where the elliptical-shaped dome would turn inside out and collapse like an umbrella caught in a strong wind—is prevented by the higher pressure of the gas in the fuel tank below.

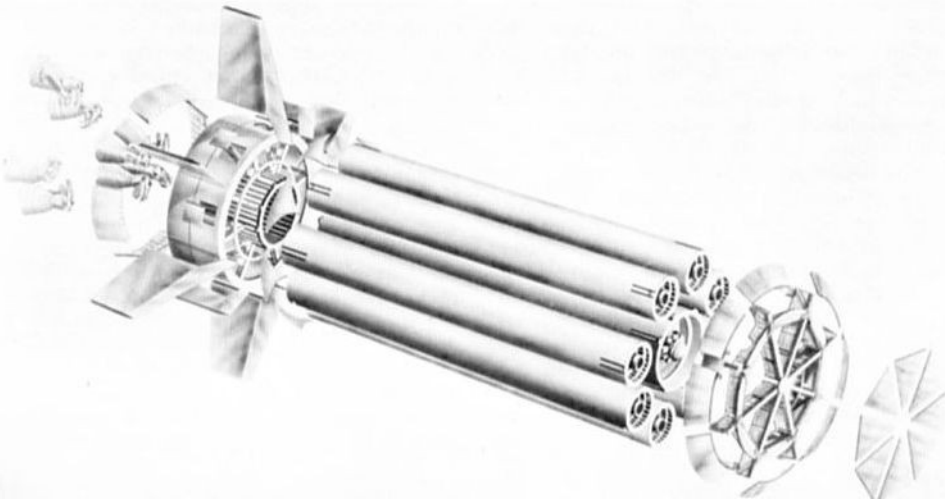


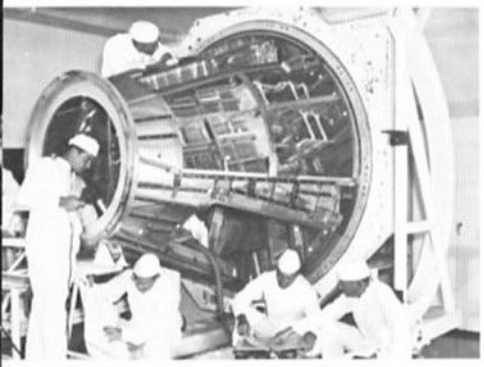
Miles upon miles of glass fiber threads are wrapped around a mandrel to form light-weight Fiberglass rocket casings. The process is computer-controlled.

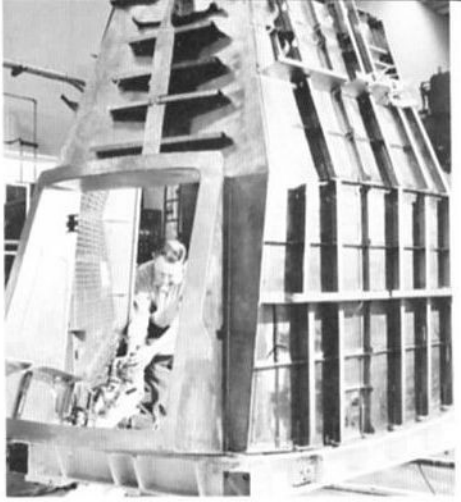
Propellant Tank Configuration

The tanks of all U.S. rockets—with the exception of one—are arranged in a tandem configuration, that is, one stacked directly on top of the other. The exception is the Uprated Saturn S-1B booster, whose nine tanks are clustered side-by-side in a circular array.

Exploded drawing of the Saturn I booster, showing tanks, thrust structure, engines, etc.







Technicians work on a Gemini capsule (above). The manned cabin is built around this wedge-shaped segment (right).

On most tandem tank arrangements, the liquid propellant from the upper tank flows into the engine compartment through plumbing lines which are routed through the middle of the lower tank. Atlas and Centaur, however, have lines which run down the outside of the airframe, by-passing the lower tank completely. The Douglas S-4 and S-4B and the North American S-2 stages, all Saturn upper stages, also use external plumbing lines.

The Chrysler S-1B stage consists of nine tanks, a center 105-in. diameter LOX tank and eight 70-in. diameter outer tanks (four fuel and four LOX) surrounding the center tank. All propellant feed lines run from the bottom of each tank and are cross-manifolded.

Why They Fly

Anyone who has ever seen an inflated balloon slip from a child's hand and fly crazily about a room, or felt a rowboat slide out from underneath him as he stepped from the boat onto a dock, has come into contact with the law of physics which makes possible rocket-powered flight—Newton's third law of motion.

Stated simply, Sir Isaac Newton's law (first expressed in 1687) said that for every action, there is an equal and opposite reaction. The action of the pressurized air rushing out of the balloon results in the reaction of the balloon skipping about the room, in the direction opposite to that of the escaping air. The movement of the boat away from the dock is a reaction to the action of stepping onto the dock. Similarly, the lift-off of a rocket is a reaction to the pressures and velocities of the exhaust gases streaming from the rocket's engines.

There are three major indices to a rocket engine's performance: thrust, specific impulse and total impulse. In a way, the first two are comparable to horsepower and fuel consumption in an automobile engine.

Thrust

Thrust is the force, measured in pounds, pushing the rocket in reaction to the exhaust of the engine's gases.

Without going into detailed mathematical formulas, the thrust of any rocket engine is determined in large part by the weight of propellants burned per unit of time and the velocity at which the resulting gases are exhausted. The thrust of the engine system must always be greater than the total weight of the launch vehicle it is supposed to drive — for example, the first stage of the Saturn V vehicle generates 7.5 million pounds of thrust, which is sufficient to lift the 6-million-pound weight of the total vehicle and push it to an altitude of more than 200,000 feet before its propellants are used up.

It is interesting to note that a rocket's thrust is derived wholly from the combustion of propellants within the engine and not—as some mistakenly believe—from the exhaust flames pushing against the outside air. If this were true, then rocket-powered flight in space—where there is no air—would be impossible.

Specific Impulse

Specific impulse is a measure of a rocket engine's power and efficiency.

It is the pounds of thrust obtained

from the burning of one pound of propellants during one second of engine operation and is expressed as lb.-sec/lb., which is frequently (and erroneously) abbreviated to "sec." Thus, an engine having a specific impulse of "420 seconds" delivers 420 pounds of thrust for every pound of propellants burned every second.

Today, 450-460 lb.-sec./lb. is about the upper limit obtainable with conventional liquid chemical rockets and about 260-275 lb.-sec./lb. is the upper limit for solid propellants.

Total Impulse

Total impulse may be considered a measure of a rocket engine's stamina, since it is the product of thrust and firing duration (in seconds).

Because time of operation depends on the amount of propellants carried in the rocket's tanks (within practical limits, most engines will continue to generate thrust as long as propellants are fed into them), total impulse really is a measure of the overall vehicle, rather than of the engines alone.

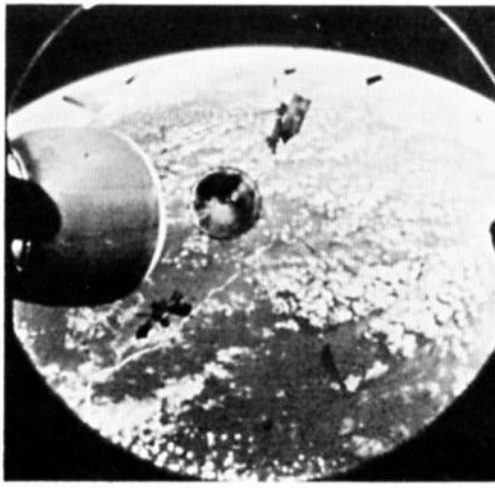
Thus, a solid-propellant rocket with 800,000 lbs. of thrust may not be the equal of a liquid-propellant rocket system of only 360,000 lbs. thrust—if the solid burns for only 10 sec. (800,000 × 10=8 million lb.-sec. total impulse) and the liquid system burns for 120 sec. (360,000 × 120=43.2 million lb.-sec. total impulse). For the solid to equal this total impulse, it would require a motor capable of burning for 50 sec. or nearly five times longer than it is now. Its size would have to be increased proportionately.

Major Propulsion Systems

With these basic guidelines in mind, let us take a look at the three major categories of propulsion systems: chemical, nuclear and electric.

Only chemical rockets (so-called because they are based on the chemical reaction of propellants) are in use today, although the space industry is working toward nuclear and electric powerplants. In fact, the time is not too far distant when scaled-down models of electric engines will be test-flown in space to gather data that will be useful in building full-size engines.

Chemical propulsion systems fall into two classes: liquids and solids. Liquid rockets predominate over solids today, although there are some applications—such as weapon systems—where solids are preferred.



Camera on the second stage of a USAF Titan II caught this shot of the first stage of falling away, after the two had separated. Note the clouds below.

Liquids owe their pre-eminent position in space today because of two principal advantages: (1), their performance is better than solids on a pound-for-pound basis and (2), their operation can be controlled (throttled down to a lower thrust level or shut down and later restated). Liquid rockets generally are more complex and more expensive than solids, which can be stored for long periods of time before using.

But the performance and the compact size of a liquid system (compared to a solid of equal performance) so far has been worth the price, in the opinion of most U.S. missile and space agencies.

Liquid propulsion rocket systems generally are categorized by two characteristics—the temperature of the propellants and the method used to move propellants from the rocket's tanks into the engines.

Cryogenic Systems

If the propellants are almost frozen —as liquid oxygen is—the system is called "cryogenic," a word which describes extremely low temperatures. If the propellants are about the same temperature as a cool day, they are said to be "storable" — a term indicating that the liquid may sit in the tanks for long periods of time without turning into a vapor as liquid oxygen will. (Storable propellants usually—but not necessarily — also are "hypergolic," which means that they burn spontaneously upon contact with each other).

If the propellants are forced into the engines by pressure only, the system is said to be a "pressure-fed" one. If moved by pumps, it is a "pump-fed" system. Although a rocket might use a mixed cryogenic-storable propellant combination, the feed systems are never mixed —it is either pressure or pump-fed.

The major parts of a liquid rocket engine and their functions are:

• **Propellant feed system.** As indicated above, the feed system is the conveyor belt which moves the liquid propellants from the rocket's tanks into the combustion chamber of the engine. Pressure-fed systems release increasing amounts of a gas—usually helium or nitrogen—from a very high-pressure reservoir (about 2,000-3,000 pounds per square inch [psi]) within the tank to force the propellants down into the plumbing lines at the base of the tank.

Pressure Fed Systems

Some pressurization systems use a balloon-like bladder which expands inside the tank under the pressure of the gas and forces the propellant out like an hydraulic piston. This approach, called "positive expulsion," prevents the propellants from dispersing throughout the tank during zero-g periods in flight, when the engine might be shut down, since the bladder is not allowed to collapse.

The major advantage of a pressure-fed system is its simplicity, since there are few moving parts—just a series of valves, normally. The major disadvantages are the heavy tank structures required to contain the high pressures and the practical limits to which it can be used in conjunction with high-pressure (above 300 psi) combustion chambers. The feed system must always be at a higher pressure than the combustion chamber if the propellants are to flow from one to the other.

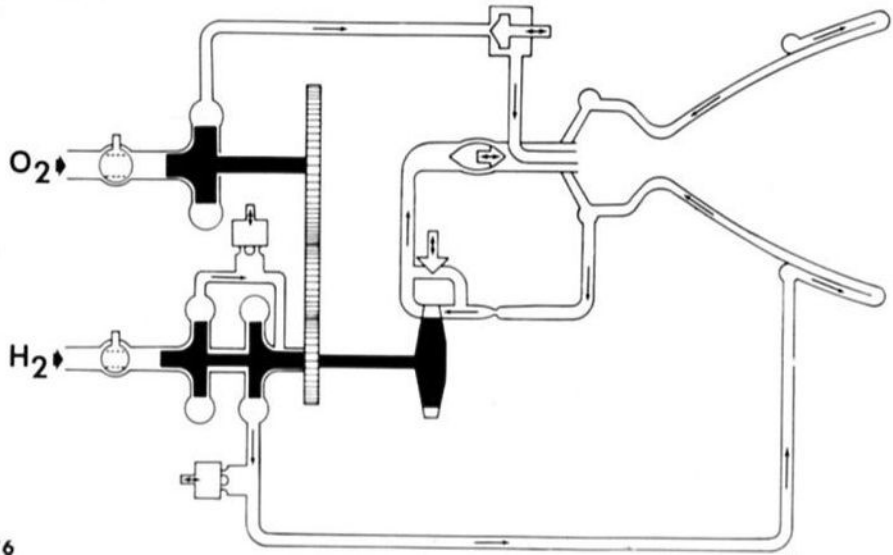
Pump Fed Systems

Pump systems, which generally resemble the agitator of a washing machine, accelerate the propellants radially off the ends of pump-blades at fairly high speeds to produce high pressures and large flow rates.

The major advantage of a pump is that it can deliver large quantities of propellants to an engine—up to 6,000 pounds per second—at far higher pressures for less weight than a comparable pressure-fed system. (Pump-fed systems, however, do require some gas pressurization within the propellant tanks to "pack" the liquid down tightly on the pump inlets). Pumps make possible combustion chamber pressures of up to 3,000 psi., but they are complex and expensive pieces of machinery.

• **Gas generator.** Used only with pump-fed systems, the generator provides a gas to drive a turbine which, in turn, drives the propellant pumps either through a direct shaft or, as is more frequently the case, through a series of

Simplified schematic of a liquid rocket engine shows how liquid oxygen (O_2) and liquid hydrogen (H_2) flow through pumps on way to combustion chamber (far right).



reduction gears.

There are several gas generators—the small monopropellant tank of hydrogen peroxide, decomposing in the presence of a catalyst to form steam, which then is directed against the blades of the turbine and the bi-propellant system which burns the same propellants as the main rocket engines, but in a small separate chamber, and then directs this exhaust gas against the turbine. While not true gas generators, there are other means of driving the turbines — such as the tap-off system, which "bleeds" off part of the exhaust from the main engine and ducts this back into the system to spin a turbine; and, finally, there is the "boot-strap" cycle, which uses the energy of a very cold fluid—such as liquid hydrogen—expanding from a liquid to a gaseous state to spin a turbine.

• **Injector.** The injector is the carburetor of a rocket engine. It usually is a flat, hollow disc with an intricate series of separate passageways inside for the fuel and the oxidizer.

The face of the injector opening into the combustion chamber has a large number of holes drilled into it (the Rocketdyne F-1 engine injector has 3,700), through which the propellants flow and are atomized into a very fine spray. The holes, or "orifices," are arranged in concentric circles alternating between fuel and oxidizer and are so angled toward each other that they mix the propellants in homogeneous combustion.

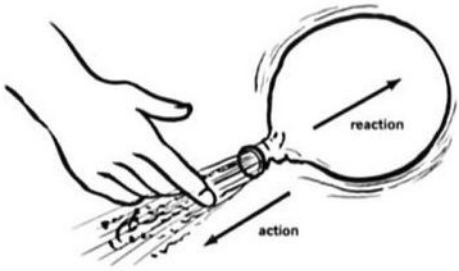
• **Igniter.** Some propellant combinations are hypergolic, i.e., they burn immediately upon contact with each other, and need no external ignition. Other propellant combinations, however, require either a spark, a small explosive charge or a small amount of hypergolic fuels to initiate combustion.

Once started, the flame in a rocket engine will feed on the propellants as they continue to flow into the chamber and no further ignition is required.

• **Combustion chamber.** Also called the thrust chamber, this is the cylinder in which the liquid propellants are mixed and burned to produce a high-pressure, high-velocity exhaust gas; it is the container for Newton's third law.

Combustion chambers roughly look like inverted milk bottles, with the injector plate (see above) at the top and the pinched-in exhaust mouth at the bottom.

A chamber is built from a series of individual hollow tubes which have been pre-formed to the outer contour of the finished engine. The tubes are placed on a mandrel, a device similar to a dressmaker's dummy, and brazed together to form the cylindrical chamber.

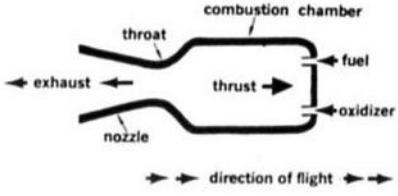


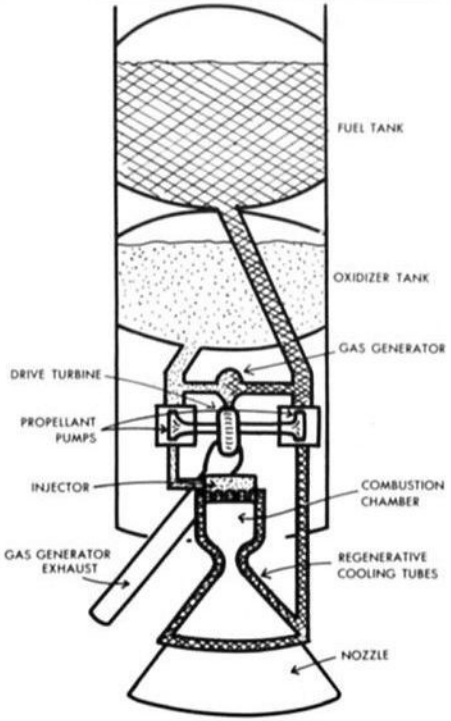
The reaction af air escaping, under pressure, from the balloon drives it forward.

The liquid fuel is routed through these tubes to cool the combustion chamber, which — when propellants are burning there — normally operates at between 4,000 and 6,000 degrees Fahrenheit. Called "regenerative cooling," this technique is similar to the circulation of water around the engine block of an automobile. But there the similarity ends, for in a rocket engine, the fuel is injected into the combustion chamber after it has been used as a coolant.

Most engines powering American rockets today operate at a chamber pressure of between 300 and 800 psi. The Rocketdyne F-1, five of which will constitute the propulsion system in the first stage of the Saturn V launch vehicle, operates at a chamber pressure of nearly 1,200 psi.

A rocket moves in reaction to the high-pressure, high-velocity gases streaming in the opposite direction.





Principal parts of a liquid rocket propulsion system are shown in this drawing.

Experimental Engines

Major liquid engine companies in the U.S. today — such as Aerojet-General Corp., and Rocketdyne, a division of North American Aviation, Inc. — are working on experimental engines operating at chamber pressures of 3,000 psi. Given two rocket engines of equal volume, weight and dimensions, the one with the higher chamber pressure will deliver more thrust and a higher specific impulse.

Like most good things, however, these high-pressure engines do not come easy. Temperature is directly related to pressure and so chambers operating at about 3,000 psi. will have temperatures between 5,500 and 8,000 degrees Fahrenheit (F).

Research work is being done on alternate cooling methods, since regenerative cooling is incapable of handling this great a heat load. Generally, these alternate techniques might be grouped under the heading of "film cooling," in which a very thin layer of fuel is sprayed down the walls of the chamber and in so doing prevents the flames from touching the walls directly.

Solutions for this and other problems associated with high chamber pressures are within reach and someday engineers will be able to couple these advanced powerplants to advanced nozzles (see below). The result will be large, heavy launch vehicles powered by small, lightweight engines.

• **Nozzle.** The nozzle is an integral extension of the combustion chamber and plays an essential role in the combustion process, since it increases the velocity of the exhaust gas streaming from the chamber. The greater the increase, the greater the reaction (thrust) of the engine.

Most nozzles today are of the conventional convergent-divergent type—that is, they are shaped something like an hourglass. The nozzle tapers in from the walls of the chamber to a narrow throat and then flares out again into a bell-shaped skirt. The tapered-in section is convergent and causes the flow of the exhaust to increase from sub-sonic to sonic speed. The divergent skirt then allows the gas, which has been compressed in passing through the constricted throat, to expand suddenly. In the process of expansion, the gas flow reaches supersonic speed and exerts a pressure on the nozzle wall.

The Ideal Nozzle

The ideal nozzle for a rocket engine is one that does not release a single gas molecule to the external atmosphere until the pressure of that molecule is exactly equal to pressure outside the nozzle —or, to put it another way, until it (the nozzle) has extracted every last bit of energy from the gas.

Since there is not that much to be gained by extracting every last possible amount of energy from the gas and since practical limitations of length and weight must be considered (the ideal nozzle would be at least as long as the entire rocket itself), a compromise ratio is selected that gives the best expansion for the shortest length and lightest weight within the pressure range the engine will find itself in.

For example, in engines used between sea level and about 200,000 ft. altitude, a ratio of between 10 and 16-to-1 (if the cross-sectional area of the engine's throat was 10 square inches, then the area of the nozzle exit would be 100 or 160 square in.) is considered optimum.

Upper-stage engines, which must operate in the vacuum conditions of space,

usually have area-expansion ratios between 40 and 60-to-1.

Practically all of the major engine manufacturers are investigating a number of advanced nozzle concepts today, such as the:

- **Air-scooping shroud,** which would be used only on first-stage boosters, is a cylindrical duct around the base of the vehicle. Open at both ends, it scoops in air as the vehicle flies through the atmosphere and then mixes and accelerates this air with the exhaust of the engines.
- **Plug or spike,** a conical body extending from the base of the rocket. The engines are arranged around the circumference of the rocket with their exhaust directed against the plug.

The plug acts as one segment of a nozzle, while the exhaust gas expands in all other directions until the pressure of the gas equals ambient pressure and so forms the other segment of the nozzle. This particular concept is called both altitude-compensating (since the exhaust will always expand to the limit of ambient pressure) and external-expansion (since the expansion of the exhaust gas takes place outside of the rocket system).

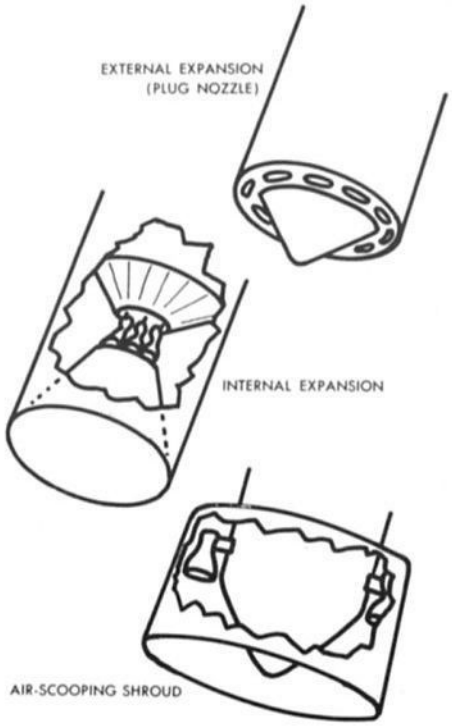
- **Internal expansion,** in which a cluster of engines, each with its own separate nozzle, exhaust their gases into a still-larger nozzle which is part of the rocket system.

This approach is particularly useful on upper-stages which operate mainly in the vacuum of space, where even the smallest pressure of the exhaust gas would still be greater than the zero pressure outside the nozzle.

While the number of propellant combinations available to missile engineers today could be numbered in the hundreds, there are only a few that are in actual use. Liquid oxygen (at −297 degrees F) and ambient RP-1, a petroleum-base fuel, combine in a 300-psi. chamber to produce a specific impulse of about 300 lb.-sec./lb. This particular combination is used in different engines by the Thor, Jupiter, Atlas, Titan-1, and the two Saturn first-stage boosters S-1 and S-1C.

Most Powerful Propellant

Liquid oxygen and liquid hydrogen (at −423 degrees F) is the most powerful propellant combination used today, delivering about 410-420 lb.-sec./lb. specific impulse. It is the propellant combination of the Saturn upper stages and the Centaur vehicle.



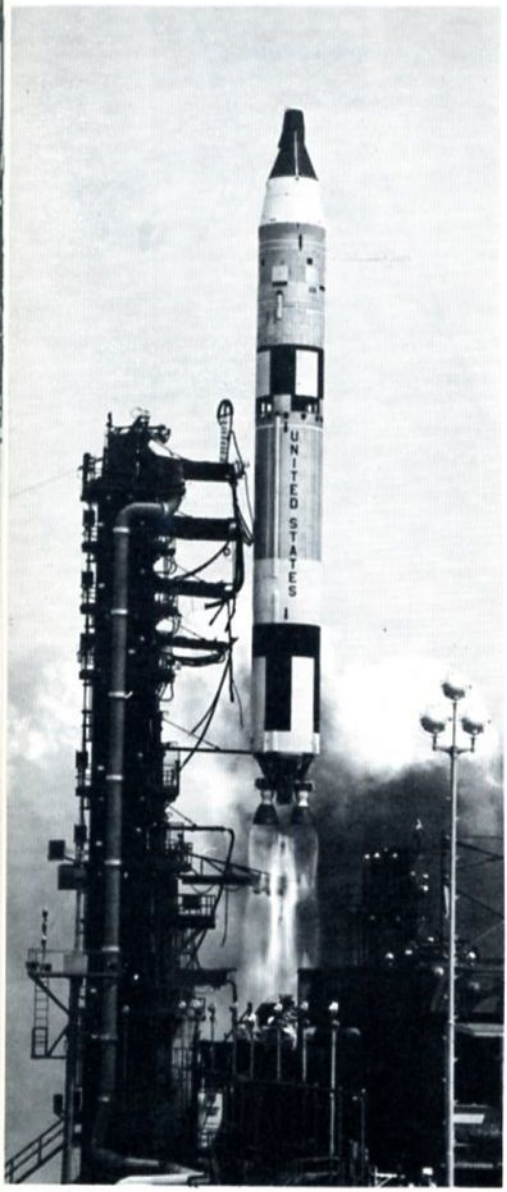
Some future boosters may use one of these advanced nozzle concepts.

There are three hydrogen-oxygen engines in the U.S. today: the 200,000-lb.-thrust J-2, the 15,000-lb.-thrust RL-10, and the Aerojet 1.5 million-lb.-thrust M-1 (still in development and not ear-marked for any particular vehicle).

Storable propellants in use today include unsymmetrical-dimethyl-hydrazine (UDMH) and nitrogen tetroxide and UDMH-inhibited red fuming nitric acid (IRFNA). The former combination, used in the Titan II launch vehicle as well as the Gemini and Apollo spacecraft, has a specific impulse of 285-330 lb.-sec./lb., depending on the altitude at which it is used. The latter, used in the Lockheed Agena upper stage, has a specific impulse of about 320 lb.-sec./lb. in the vacuum conditions of space.

All liquid rocket engines in use today are gimballed, i.e., they can be swivelled back and forth and from side to side to provide directional control of the vehicle which they are driving.

This is accomplished by making the engine mount, where the powerplant attaches to the airframe, flexible. At least two hydraulic pistons, called "actuators," hold the engine steady during stable



The first Gemini spacecraft, minus astronauts, was flown aboard a Titan II Apr. 8, 1964. Note the clear flame of the vehicle's exhaust.

flight. But when the vehicle's guidance system dictates course changes, these actuators are commanded to deflect the engine a corresponding amount off center, like a ship's rudder, to change the vehicle to the desired heading.

Solid Propellants

As the name implies, solid propellants have a definite shape and a consistency. Most solids look and feel like a hard rubber. As do their liquid counterparts, solid rocket motors carry their own fuel and oxidizer to produce a high-velocity, high-pressure exhaust gas.

But where liquid systems carefully separate the propellants in separate tanks, solids mix both together in one homogeneous mass — called a "grain." Non-hypergolic elements are chosen for solid propellants, so that the grain may be formulated and handled without undue fear of an explosion.

Solids always require an external source of ignition but, once burning, will feed on themselves.

Solid motors are inherently simple devices — in fact, the first known rockets were solid gunpowder missiles built by the Chinese during the 1200s. A solid motor includes a case — which serves double-duty as a propellant container and a combustion chamber, a nozzle, a grain, an igniter and a thrust vector control system.

Like liquids, solids also can be divided into two major groups: double-base and composite. A double-base propellant essentially consists of two prime ingredients, each of which contains both fuel and oxidizer molecules — such as nitroglycerin and nitrocellulose. Each contain enough fuel and oxidizer particles within itself to burn independently of the other. They are blended together because, as a pair, they are more stable than either one alone and their energy release is greater when working in consort.

Composite Solid Propellants

The second stage of all three versions of the Navy's Polaris fleet ballistic missile, A-1, A-2 and A-3, use a double-base propellant combination, as well as the third stage of the Air Force's Minuteman ICBM.

A composite solid propellant consists of separate and distinct fuel and oxidizer elements, held together by a third element called a "binder." Composite propellants frequently contain a very finely-powdered metal — usually alumi-

A manned Mercury-Atlas launch.

A completed J-2 rocket engine (left), with its pumps and lines installed. The basic engine structure is built up from a series of hollow tubes (right).

num — which, when burned along with the grain, increases both the temperature and mass of the exhaust gas and, in so doing, increases the motor's specific impulse.

Composites generally have slower burning rates than double-base grains, but have higher specific impulses.

The first stage of the Navy's A-1 and A-2 Polaris, the first two stages of USAF's Minuteman ICBM, the Army's short-range Pershing, the two 80-foot-long boosters of Air Force's Titan-3 space launch vehicle, and the retro-rockets on the Mercury and Gemini manned spacecraft all burn composite propellants (but not the same formula).

Since the thrust of a solid is dependent on the amount of gas flowing in the case at any given instant, the shape — or configuration, as engineers like to call it — of the grain plays an essential part in a motor's performance. The more of the grain's surface exposed to the flame, the more gas will be generated and the greater the thrust of the motor.

The shape of the grain also figures importantly in the burning rate of the motor (aside from the type of propellant), since the more of the surface facing the flame, the faster it will be consumed.

For these reasons, most grains today are cast with either a star-shaped or circular cavity running the length of the case. The star grain provides the greatest burning surface and therefore the greatest thrust; it is the configuration favored by the military services for fast weapon systems, where speed — in reaching the target — is critical.

The circular center-hole is the best compromise between maximum thrust and long burning time; it would be favored for solid motors used as the booster of space launch vehicles. Both the Aerojet-General Corp. and Thiokol Chemical Corp. today are building experimental 260-in. diameter motors, with circular center-holes, which might someday be used as space boosters.

Thrust Vector Control

Solid propellant motors cannot be used, as liquid propellant engines are, to provide directional control of a rocket since motor and airframe are integral and the former cannot be swung back and forth like a rudder. Directional control, or "thrust vector control" as it is more properly called, is obtained by one of several ways:

- **Jetavator.** This is a ring, suspended from the base of the motor case by several hydraulic actuators, around the lip of the exhaust nozzle. As the guidance and control systems calls for changes in the vehicle's flight path, the actuators push the ring down into the exhaust and the gas, striking it, causes an imbalanced force in the direction of the jetavator. The vehicle then turns into the direction of the imbalanced force.
- **Jet vanes.** These are moveable wedge-shaped blades attached to the

inside of the nozzle. The guidance and control system commands their movement within the gas stream to create imbalanced forces. Some missiles, such as the Army-Martin Co. Pershing, augment these vanes with aerodynamic control surfaces on the external airframe.

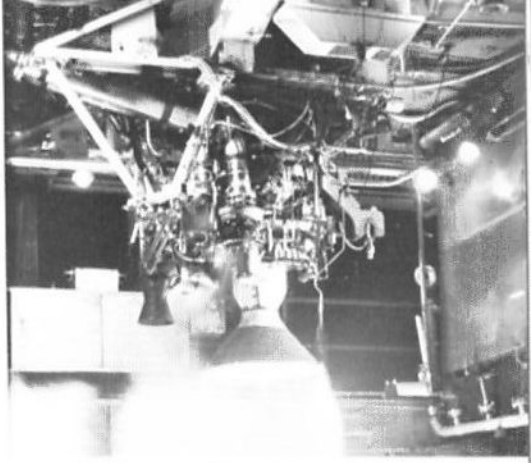
• **Movable nozzle.** This method, the closest to the gimbal action of a liquid engine, breaks the nozzle into two segments — one fixed and immobile and the other hinged. The hinged nozzle skirt then can be swung back and forth by actuators to deflect the exhaust in whatever direction the rocket is to be steered. This method is heavy and intricate, since the joint between segments must be sealed to prevent leakage. Some companies have had reasonable success with metal bellows in the joint.

• **Secondary injection.** So-called because a secondary fluid (either another gas or, as is more commonly the case today, a liquid) is injected into the exhaust flow from the solid motor, this method of thrust vector control works in much the same way as jet-vanes. The fluid is forced into the exhaust from a series of orifices around the nozzle and creates a shock wave within the gas stream, as well as increasing the density of the flow inside that wave. The result is, again, imbalanced forces and the rocket turns into the direction of the imbalance.

Hybrid Motors

Some companies and government agencies are investigating hybrid motors, which are part solid and part liquid. These cross-breed powerplants attempt to achieve some of the performance and compactness of liquid propellants with the simplicity and low cost of solids.

A typical hybrid motor would consist of a solid grain, fuel-rich, and a tank of liquid oxidizer immediately above it. The liquid oxidizer would be squirted down the length of the solid grain and,



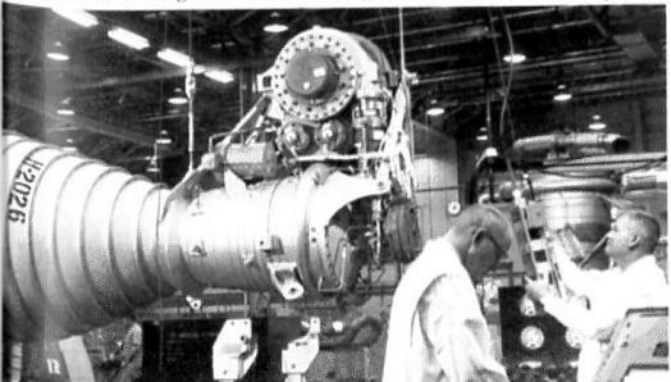
A static firing a Titan II engine, minus its nozzle skirt extension.

the two elements being hypergolic, burst into flames. The motor could be controlled simply by shutting off the flow of the oxidizer and re-started by opening the valves again.

Nuclear Systems

For the more ambitious space projects being considered 10 and 25 years from now — such as flights to the planet Mars (42 million miles away from earth) or satellite probes to the planets Jupiter (391 million miles away) or Saturn (almost 800 million miles away), the United States is looking to nuclear and electric propulsion systems to provide the thrust required.

To attempt such missions with chemical rockets — even the most advanced chemical systems — would require vehicles weighing millions of pounds and flight times measured in decades, if not complete lifetimes. Velocities on the order of 50,000 to 125,000 miles per second (mps.) — (the first manned trip to the moon will be made at a speed of about 7 mps.) are necessary — and only nuclear or electric systems can deliver speeds such as these.

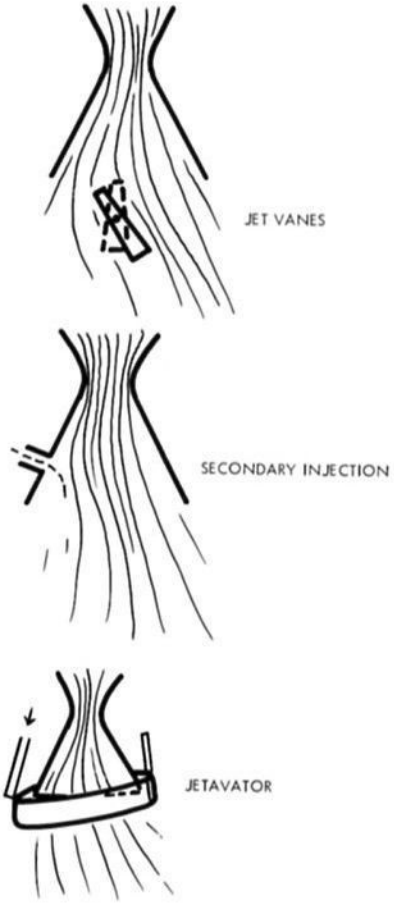


Overhead crane lifts an H-1 engine, eight of which power the Saturn I first stage. Machinery at top of engine is the pump subsystem.

Thor Able Star lifting off.

Snark, an early cruise missile. ▶

U.S.AIR FORCE



Various types of thrust vector control used by solid propellant motors include jetavators, secondary injection, jet vanes and moveable nozzles.

Heat transfer, rather than combustion, is the means used by a nuclear engine to generate a high-velocity exhaust gas. The specific impulse of a nuclear engine is directly related to the temperature of the reactor (reactors generate tremendous heat) and inversely related to the molecular weight of the exhaust gas.

The lighter the gas particles, the easier and faster it is to expel them from the engine. The higher the temperature, the more energy can be imparted to the gas. And although it might seem strange that such high specific impulses (between 800 and 3,000 lb.-sec./lb.) can be obtained without burning two elements together, it should be remembered that combustion in a chemical engine is only a means toward an end. It is the pressure and velocity of the gas exhausted from the engine that matters — and not the method used to generate that gas.

A nuclear reactor uses its tremendous heat to boil a single propellant, called the "working fluid," usually liquid hydrogen (because of its low molecular weight), causing it to pass rapidly, almost instantly, from a very cold liquid to a very hot gas. When the working fluid is then expanded through a convergent-divergent nozzle, this thermal energy is converted to kinetic energy and the gas escapes at extremely high velocities.

There are three main types of nuclear propulsion systems, depending on the type of reactor:

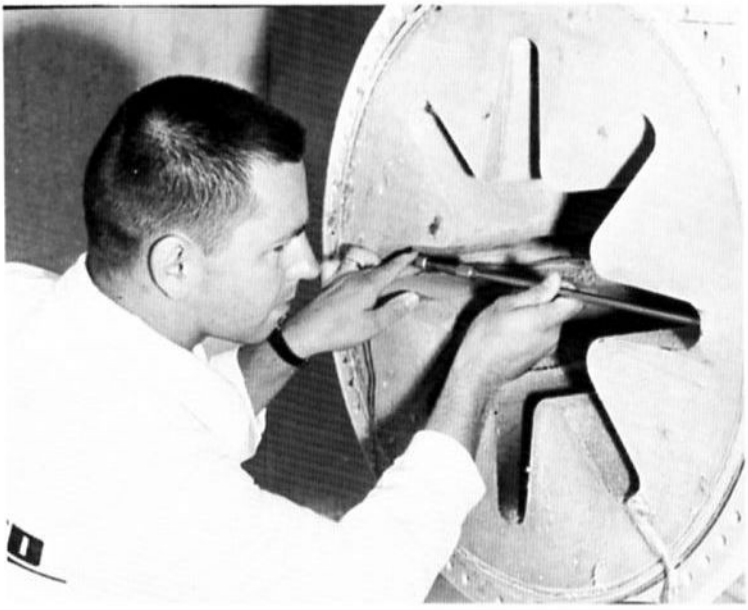
• **Solid-fuel reactor.** The fissionable nuclear matter is enclosed in a drum-shaped solid core with a series of ducts running through the core. The working fluid flows through the ducts where it is heated and then, emerging from the base of the core, is expanded through a nozzle.

This is the type of reactor and propulsion system on which the Atomic Energy Commission has done research work under Project Rover and NERVA (Nuclear Engine for Rocket Vehicle Application). Specific impulse would be between 800 and 1,000 lb.-sec./lb.

• **Liquid-fuel rector.** In a reactor of this type, the working fluid would be bubbled through a liquid uranium solution to be heated and then expanded through a nozzle. It is a complicated system, although specific impulses between 1,200 and 1,500 lb.-sec./lb. are theoretically possible.

• **Gaseous-core reactor.** The most promising of the three types and the one with the most difficult engineering problems to solve, this nuclear powerplant would mix the working fluid directly with the fissioning (atom-splitting) uranium in the same chamber. The resultant temperatures would be such as to be beyond the melting point of any materials known today.

Suggestions have been advanced to contain the reaction with very powerful magnetic fields, but initial attempts to do this have not been very successful. The lure of specific impulses between 3,000 and 4,000 lb.-sec./lb., however, is strong enough to sustain continued ef-



Technician examines the precision of a solid-propellant cast. The eight-point star configuration seen in this grain is typical of many solid motors.

forts to find solutions to the many problems involved with this type of a reactor.

Since the thrust of these nuclear powerplants would be approximately the same as that of a chemical system required to drive the same stage weight, the difference in specific impulse (anywhere from twice to 10 times greater) between a chemical and nuclear system takes on added significance.

A chemical engine, delivering 200 000 lbs. of thrust with a specific impulse of 400 lb.-sec./lb., would burn about 500 lbs. of propellants every second. A nuclear engine, with a specific impulse of 1,000 lb.-sec./lb., would extract approximately the same thrust from about 200 lbs. of a single propellant every second of burning time.

Electric propulsion systems have two major characteristics — very low thrusts and extremely high specific impulses — which make them very well-suited as the powerplants of deep-space probes, where the pull of gravity will be almost non-existent and a small force will be sufficient to move vehicles of large mass. Upper stages powered by one of the various types of electric engines (see below) would first have to be placed in orbit by conventional chemical boosters before they could demonstrate their unique advantages.

Electric Propulsion Systems

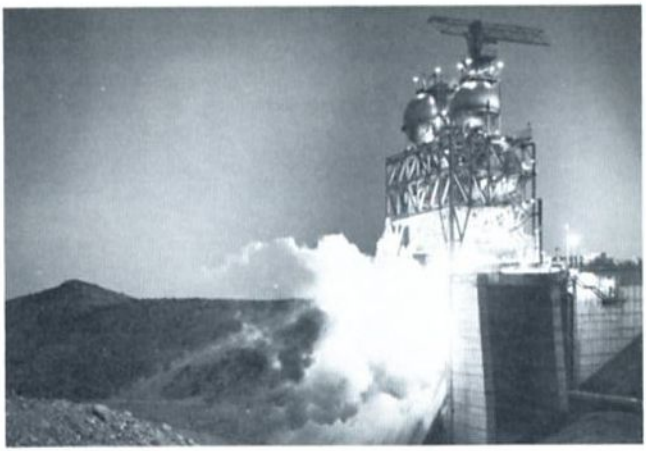
Like nuclear engines, electric propulsion systems can be grouped in three main classes:

• **Electrostatic.** This category of engine makes use of the fact that particles with the same electrical charge repel each other.

The engine first heats an easily-ionized propellant, such as cesium or mercury, and then passes this working fluid across a high-voltage grid. As the gas comes in contact with the grid, it becomes ionized — that is, it loses electrons (which flow onto the grid) — and thus acquires a positive charge.

Immediately down-stream of the grid is a positively-charged electrostatic field. The field varies in strength, with an

A missile explosion, now a rare sight.



A mighty F-1 rocket engine, building up 1.5 million lb. of thrust, lights up the sky with its flame and fills the air with its thunder during a night static firing.

extremely high charge near the grid and tapering off to no charge at all near the exit nozzle. The positive gas ions are repelled by the strong positive field and flow in the direction of least force — toward the nozzle.

As the ionized gas streams from the chamber, two or more "electron guns" return the electrons and neutralizes the charge.

The thrust of electrostatic engines generally runs between 1 and 15 millipounds (a millipound is 1/1,000th of a pound) and their specific impulse falls between 1,000 and 16,000 lb.-sec./lb. The conversion efficiency (the percentage of the power put into the engine that is turned into usable thrust) averages around 70-75%.

• **Electrothermal.** This type of electrical engine uses electricity either in the form of an arc or a resistance coil to heat a working fluid to temperatures between 5,000 and 6,000 degrees F.

The arc-jet is one of the oldest electric engines on which research has been conducted; basically, it consists of two electrodes inside a thrust chamber. As the working fluid (almost invariably hydrogen, but some companies have experimented with ammonia) passes between the electrodes, an arc is drawn across the gap and the propellant is both heated and accelerated out an expansion nozzle.

In another form, the propellant is made to flow over a resistance-heated tungsten coil in order to be heated and then accelerated.

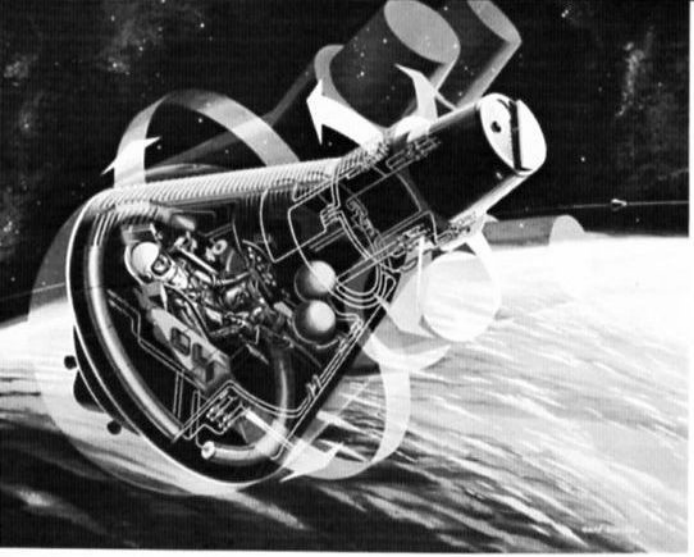
Thrust of electrothermal engines usually runs between 100 and 500 millipounds, their specific impulse between 700 and 2,000 lb.-sec./lb., and their conversion efficiency about 45%. In overall performance, the electrothermal engine tends to run a poor third to the other two types.

• **Electromagnetic.** As gaseous-core reactors are the most promising type of nuclear powerplants in the future, electromagnetic engines show the greatest potential in the field of electric propulsion.

These engines have thrust ratings — between 100 and 500 millipounds — which compare favorably with those of electrothermal engines and specific impulses — between 1,500 and 10,000 lb.-sec./lb. — which compare well with those of electrostatic systems. Their conversion efficiencies are not as impressive — 30% is about standard — as electrostatic units, but continued research is pointing toward a day when as much as 60% efficiency might be achieved.

Electromagnetic engines use rapidly-varying magnetic fields to accelerate a plasma* to high velocities. The engine ionizes the single-propellant gas by passing it over a high-voltage grid, similar to that found in electrostatic engines, but does not draw off the electrons. The gas — now a plasma — then enters a chamber which is wrapped in a series of electrical coils. These coils create magnetic fields which attract the plasma — like a carrot dangled in front of a

*Plasma is defined as a gas which contains neutral, positive and negative particles all in the same gas. Although the ions and electrons are separate and normally would combine to form neutral particles, they remain separate in a plasma. They balance each other, however, so that the over-all charge of a plasma stream is zero.



Transparent drawing shows the reaction control system of the Mercury capsule; astronauts fired the system's small jets to turn themselves around three axes.

donkey — until the gas is led out of the nozzle at very high speeds.

Reactor Use In Electric System

The one drawback to electric engines is that they require considerably large quantities of electrical power to drive the grids, coils, and other equipment needed to provide the initial driving force. Nuclear reactors generally are intended to be the power source since the power requirements tend to run toward the high side — upwards of 150 kilowatts. Actually, the reactor provides thermal energy which then must be converted into electrical energy by still another element in the over-all system.

Like liquid chemical systems, electric engines are complex and heavy systems. However, they offer exceptional performance to compensate for this complexity.

Electric engines probably will first be used as the stabilization systems of satellites operating in earth orbit — such as a communications satellite in synchronous orbit — where the requirement will be for a small-thrust engine capable of operating for long periods of time on small quantities of fuel. But eventually, these small electric engines will be grouped together — perhaps in clusters of several dozens — to provide a cumulative thrust of 25 to 50 lbs.

With their high specific impulse, these engines will be able to extract nearly the last possible bit of energy from every ounce of propellant used and so will be able to do more than even nuclear engines, given the same amount of propellant.

And while the thrust of an electric engine — or even clusters of electric engines — is not very great, the engines can be run continuously for days at a time and in this way provide the accelerations required by a Jupiter- or Saturn-bound satellite.

Beyond electric systems, engineers and scientists are looking at propulsion systems which somehow would collect the enormous quantities of free energy distributed each second by the sun and then transform it into propulsive thrust. The specific impulse of such systems would be measured in at least hundreds of thousands, and perhaps millions, of pounds of thrust per second for every pound of energy used.

But unless some brilliant young scientist comes up with a practical way of harnessing this energy, these must be considered as far-future sources of propulsion.

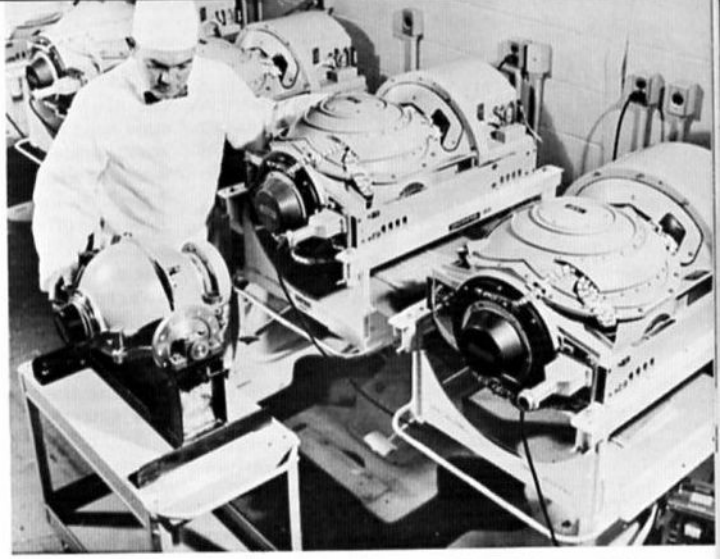
Guidance and Control

The precision which characterizes so much of space technology is an essential element of guidance and control.

Guidance and control are to a space vehicle what a compass and rudder are to a sailing ship. Although separate and distinct from each other — guidance frequently is called the brain of a system and the control system is called its muscles — they must work together, for the most accurate guidance system in the world is worthless if its directions are not followed.

Three Planes of Movement

Before examining the principal types of guidance and the way in which each



Guidance systems for the Polaris fleet ballistic missile are readied for shipment to the Navy. The five units in the background guide the earlier A-1 and A-2 Polaris missiles; the unit in the foreground is one-third smaller and two-thirds lighter—it is an advanced systems and is used on the A-3 missile.

works, it would be well to review briefly the three planes in which a space vehicle moves — under the direction of its guidance system:

- **Pitch** is the up-or-down movement of a vehicle around its lateral axis.
- **Roll** is the clockwise or counterclockwise rotation of a vehicle around its longitudinal axis. This is the one axis of a rocket vehicle which the layman can most easily identify — it runs the length of the launch vehicle, from base to nose.
- **Yaw** is the right-or-left sideways movement of a vehicle around its vertical axis.

It sometimes is hard to distinguish the pitch and yaw axes from each other, since a wing-less, symmetrical cylinder seemingly has no particular orientation. Using the vehicle's flight trajectory as a reference line is the key: any dips above or below that line would be called pitch movements. Any turning motions to the right or left of that line would be called yaw movements.

Three Types of Guidance

While there are at least eight different types of guidance, only three—radio-command, inertial, and celestial-inertial—are used in space systems.

Radio-command is the most accurate of the three, but involves a sizeable ground-based segment. Inertial is simpler and is favored for military applications since it is wholly-contained within the vehicle and cannot be jammed by an enemy. It is not, however, as accurate as radio-command. Celestial-inertial is best suited for operations beyond the earth's atmosphere and, in fact, will be used by American astronauts in their flight to and from the moon.

The dividing lines between these systems and their applications, however, are not very sharp. The Titan II booster can, if necessary, use the inertial system in the Gemini spacecraft as an emergency unit to its primary radio-command system.

The Saturn V/Apollo vehicle will be equipped with two guidance systems—an inertial system for the Saturn V launch vehicle and a celestial-inertial system for the Apollo spacecraft.

Finally, the U.S. Air Force used a celestial star-tracking guidance system on two missile weapon systems, one of which traveled entirely within the earth's atmosphere.

Radio Command

Two radio-command systems have operated on the Air Force Eastern Test Range—the General Electric/Burroughs and the Bell Telephone Laboratories systems. The GE/Burroughs system has guided the Atlas D-series ICBM, the Mercury-Atlas and Gemini-Titan II manrated launch vehicles, and the Atlas-Agena satellite booster. The Bell system guided the Titan I ICBM during its now-completed flight test program and is still used on the Range for the satellite-carrying Delta launch vehicle.

As with any remote-control system, which a radio-command system essentially is, the large part of it is to be found on the ground and only a small segment flies with the launch vehicle or missile.

Inertial gyro, key element in the Apollo guidance system.

The precise location of the system's ground-based antennas and transmitters must be very carefully pin-pointed, since guidance cannot tell a missile how to get from point "A" to point "B" if it does not know exactly where point "A" is.

The ground-based portion of a typical radio-command system includes a very high-precision tracking radar, which determines the vehicle's range (distance from the radar); elevation angle (degrees above horizontal) and azimuth direction, or compass bearing); an L-shaped rate system, which measures the vehicle's speed, and the all-important computer and associated electronics.

The airborne equipment includes two transponders (a word derived from two others—TRANSmitter and resPONDER; it is a combined transmitter and receiver which automatically sends out an answering signal every time it receives an inquiring signal from ground stations), a decoder and an antenna.

Auto-Pilot

The first few minutes of a launch vehicle's flight—such as that of the Atlas, Delta or Titan—usually is controlled by an autopilot. The autopilot basically is a gyro-stabilized platform and flight-control system which steers the vehicle, during the early part of flight, in respond to commands issued by a programmer —basically a tape recorder. It (the autopilot) also can "feel" such disturbing forces as wind gusts and correct for them.

Once the rocket vehicle has reached an altitude where the tracking antenna can see it clearly without picking up any scattered transmissions from other sources close to the ground, the ground-based radar transmitter begins sending a series of short pulses to the vehicle.

Received over the missile's antenna, these "asking" pulses are promptly answered by pulses from the vehicle's transponder. An electronic bond—called "lock-on" by engineers—is forged between ground radar and flying vehicle so that the antenna continues to follow the latter's flight.

By measuring the time between outgoing and in-coming pulses, the computer can calculate the distance between the radar and the vehicle to within a few feet of its actual position. Very precise instruments also measure the amount of angular movement the antenna has had to make to keep its lock on the vehicle; this data is used by the computer to determine the vehicle's elevation angle. Similar instruments note how far the antenna has rotated around its pedestal to continue facing the vehicle; the computer uses this information to determine the azimuth of the flying vehicle.

Rate Sub-System

Simultaneously, while the tracking radar is working out the position of the vehicle thundering overhead, another key element of the guidance system—called the rate sub-system—is clocking its speed.

This sub-system consists of another radar transmitter and three antennas, laid out in an "L"-shaped pattern. The transmitter and one of the antennas are located at the joint of the L, with the other two antennas (which can receive signals only) at the ends of the legs of the L, several thousand feet away.

The transmitter sends a signal to the second of the vehicle's transponders, which replies by sending back a signal of its own. This return signal is received by the three antennas but—because they are widely separated from each other—it "sounds" different to each one. This difference is the Doppler-shift* of the transmitted frequency and it can be correlated with velocity and direction.

*Doppler effect is the apparent change in the frequency or pitch of a signal, as the distance between the source of the signal and the receiver of that signal changes. The most familiar example is that experienced by the train passenger listening to the clanging bell of a crossing gate. The clanging of the bell seems to get higher in pitch as the train speeds closer to it and then drops off abruptly as the train speeds by.

This velocity information is combined with the positional data provided by the tracking radar in the computer, which then can calculate the necessary pitch and yaw corrections. The missile is thus guided to a distance, altitude, angle and speed where, when thrust is terminated, its separated nose cone will fly along a free-falling arc to the target; this is the ballistic trajectory of ICBMs.

If the vehicle is a space launch booster, the same procedures are followed, except that the velocity would be greater and the cut-off angle and altitude different.

All these mathematical computations are done in an incredibly short time—the Burroughs digital computer* can make as many as 20,000 different calculations every second to determine the position, altitude, bearing and speed of a launch vehicle.

Planned Trajectory

These calculations, which are accurate to within a fraction of 1%, then are compared against the figures of the pre-planned trajectory for that particular mission. The pre-planned trajectory consists of a series of guidance equations in the computer's memory section; the equations spell out where the vehicle should be at each second in the flight, which way it should be headed and how fast it should be moving.

The computer compares the actual data, as indicated by the radar system, with the desired values and any difference between the two becomes the basis for a corrective guidance signal. The computer determines the nature and extent of the correction and translates this into a coded signal, which then is sent to the vehicle by the radar system transmitter.

Upon receipt of the corrective signal, the vehicle's de-coder unscrambles the code into a series of meaningful voltages and feeds them into the control system. The process is repeated constantly throughout the course of the powered flight.

The command link between the computer through the tracking radar to the vehicle also is used to transmit staging commands to multi-stage vehicles and to command jettisoning of the protective shrouds fitted over satellites. These shrouds protect the satellites against aerodynamic heating and buffeting during the super-sonic ascent leg of the launch vehicle's flight.

Inertial Guidance

Inertial guidance, as the name implies, is based on Newton's law of inertia—a body at rest tends to remain at rest and a body in motion tends to remain in motion, unless acted upon by some external force.

Basically, any inertial system consists of a stabilized "platform," a series of accelerometers, an airborne computer and associated electronics.

The stable platform is held in the same position during the the flight as it was at rest on the pad by three gyroscopes (one for each axis, pitch, roll and yaw). Accelerometers, tied into this stable reference point, measure all acceleration forces acting on the vehicle in any direction.

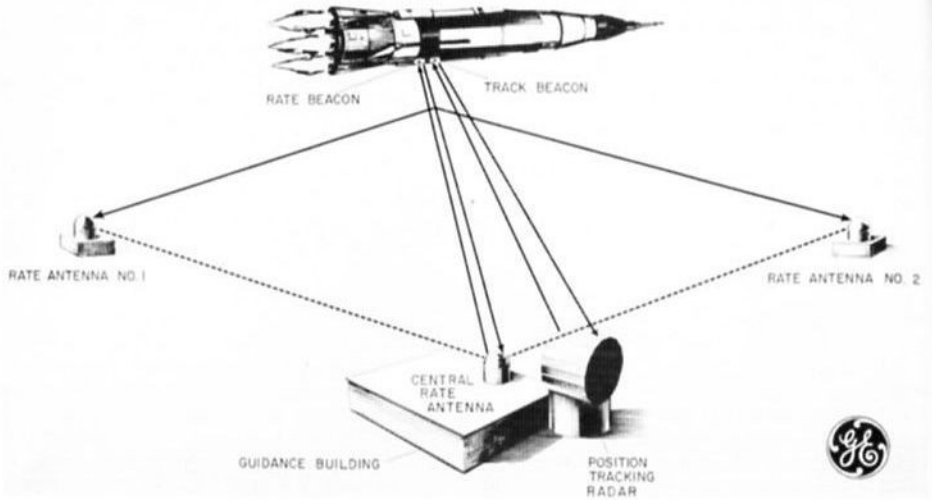
Some accelerometers are simply small weights suspended at opposite ends by very fine springs; as an accelerating force acts on the weight, it "gives" in the direction of the force, stretching the spring on one side and compressing the other. Other devices use a pendulum-like mass which rotates around a shaft when exposed to an accelerating force. Still others are built around a wire, vibrating like a plucked violin string, which changes frequency when a load is placed on it.

Accelerometers

Accelerometers, whatever their type, must simultaneously be both rugged and delicate pieces of machinery. Some are called upon to indicate forces as slight as 8/10 000ths of a "g" (a physics term equal to the force of gravity—32.2 feet per second every second and used as a measure of acceleration or deceleration) and yet must be rugged enough to measure 10 g's.

The tremendous range between 0.0008 and 10 g's may be judged from this example: if a car were capable of it, it could—at 10 g's—accelerate from a complete stop to 60 mph. in one-fourth (¼) of a second. At 0.0008 g's,. it would take

*Computers are such complex pieces of machinery that no attempt will be made here to explain their fine details. Roughly speaking, analog electronic computers may be said to use voltages proportional to the quantities being calculated — such as 1 volt for 5,000 miles per hour, 2 volts for 10,000 mph., etc. Digital computers, faster and more precise than analogs, use a binary code (only the numbers 0 and 1) to form electrical mathematical equations. Thus, in a four-bit "word" (a bit is one character, or piece of information, either 0 or 1), the numeral "zero" would be expressed as 0000, "one" would be 0001, "two" 0010, "three" 0011, "four" 0100, "five" 0101, "six" 0110, "seven" 0111, "eight" 1000, and "nine" 1001.



Simplified sketch of the lay-out of a radio-command guidance system.

about 30 hours to hit 60.

Accelerometers usually generate electrical signals which are proportional to the amount of the accelerating force acting on them. These signals are fed into the system's airborne computer and there "integrated"—or added.

The integrator, comparable to an automobile's speedometer, is an instrument which constantly adds up all the small units of acceleration reported by the accelerometer to come up with a speed (velocity*) value for any given instant during the flight. This can be done in several ways, but perhaps the simplest is to use the electrical signal from the accelerometer to drive a small electric motor. This motor is pre-calibrated so that certain revolutions-per-minute (rpm.) levels equal certain velocities.

If this motor, in turn, is used to drive a second motor, whose rpm. counter is calibrated in terms of distance, then both velocity and distance can be obtained from that single accelerometer reading.

Airborne Computer

The airborne computer is a key element in an inertial system. Using a carefully pre-planned flight trajectory stored in its magnetic "memory," the computer generates steering commands to the autopilot when the tape calls for them. The accelerometers sense these changes and report them back to the computer. The computer compares the reported change against the pre-planned change and, if they do not match, signals are sent to the control system to move the missile until they do match.

Inertial systems generally run several hundred pounds heavier than the airborne segments of a radio-command guidance system, simply because everything that makes an inertial system run must be carried along with the missile or launch vehicle. Their accuracy is slightly less than that of a radio-command system, but more than adequate for military purposes.

Celestial-Inertial Systems

Celestial-inertial systems basically are inertial guidance units augmented by a very precise optical tracking system. Two Air Force missiles, both now defunct, the air-launched Skybolt and the winged Snark, used star-tracking all-inertial systems. The inertial segment provided velocity and distance data which was correlated with the positional-reference data obtained from the star-tracking optical segment.

For the adventurous flight which Americans shortly will make from earth to the moon and back, a celestial-inertial system will provide guidance and navigation in that Apollo spacecraft. Designed by the Massachusetts Institute of Technology (MIT), the system has these major parts and contractors:

*Velocity and acceleration are not the same thing. Velocity is a constant speed — so many miles per hour or so many feet per second. Acceleration is a rate of change in velocity — so many miles per hour per second, or more commonly, feet per second per second.

• **Optical system** being built by Kollsman Instrument will be able to tell the moon-bound astronauts where they are in space by determining the spacecraft's position relative to known stars and planets.

Astro-Navigation

The astronaut-navigator will use a scanning telescope to sweep through a large part of the sky to find the star that he wants. Then, switching over to an adjacent sextant, the navigator will "lock" on the star.

Using a small control stick, he then will "lock" another sextant on a known landmark of either earth or the moon and then manipulate the stick until both images are super-imposed on each other. Pushing a "mark" button, the navigator will command the computer to determine the angle between the landmark and the star and thereby find the spacecraft's position at that point in the flight. These fixes will be taken regularly, although not continuously, throughout the flight to the moon.

• **Inertial measuring unit,** being developed by AC Electronics, consists of a gyro-stabilized platform and double-integrating accelerometers. Its function is similar to that of a typical inertial system just described. AC Spark Plug also has the additional responsibility of assembling all these parts together to make a complete guidance and navigation system.

• **The computer** is a general-purpose digital machine being built by Raytheon Corp. Two of these machines will be carried in the spacecraft for safety's sake.

The most accurate guidance system is worthless if its commands are not accurately carried out. Execution of the system's corrective commands are the responsibility of the control system, also called the "autopilot."

The Control System

Usually a combination of electronic equipment and either hydraulic, pneumatic or electrical actuators, the autopilot receives the guidance corrections as a series of coded electrical pulses. The "logic" element of the autopilot routes the signal to the appropriate actuator, which extends to a length proportional to the strength of the signal. In extending, the actuator pushes the engine off the vehicle's centerline and the effect is comparable to deflecting a ship's rudder to one side — the vehicle turns.

Technician plots the course of a missile on a plexiglas board in Central Control at Cape Kennedy.

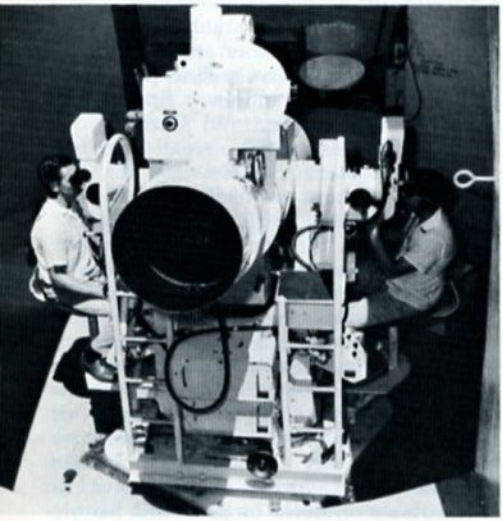
Some vehicles have small engines of about 1 000 pounds thrust, called "verniers," which provide very fine positional and velocity corrections. Spacecraft, such as the Mercury and Gemini and Apollo capsules, carry small engines called "thrusters" whose 25 to 100 pounds of thrust is used to face the craft in certain positions. The spacecraft reacts to the force of the thruster by turning in the opposite direction, which explains why such units are called "reaction control systems."

Solid-propellant motors, as we have seen, use jetavators, jet-vanes, movable nozzles or secondary injection to control their powered flight. All, however, use some form of electronic "middleman" to convert the guidance signals into activating forces for a valve, a switch, a servo-motor or hydraulic piston.

Mobile tracking system is contained within this series of vans.

A mobile cine-theodolite, used to monitor the flight of missiles.

Two operators follow the flight of a missile with a telescopic instrumentation camera.



Tracking, Telemetry and Communications

Tracking, telemetry and communications are separate elements of space technology which are woven together to form an information link between man and his machinery. The most accurate tracking system ever devised would be worth little if, after pin-pointing the location of an orbiting satellite, there was no way to collect the data gathered by the satellite. Similarly, the most comprehensive telemetry system aboard a satellite would be reduced in value if ground stations were unable to find the satellite and aim their receiving equipment at it.

The "Nets"

The United States maintains several tracking networks (usually called "nets" by the people who work with them) around the world today:

- **Air Force Eastern Test Range,** consisting of 13 stations and extending from Cape Kennedy on the east coast of Florida
- **Air Force Western Test Range,** consisting of eight stations and extending from Vandenberg Air Force Base in California more than 4,400 miles into the Pacific Ocean.
- **Manned Space Flight,** consisting of 16 stations (some of which are regular Atlantic and Pacific range stations) and extending around the world. Stations are located at Cape Kennedy, Fla.; Grand Bahama Island; Grand Turk Island; Bermuda; the Canary Islands; Kano, Nigeria; Zanzibar; Canarvon and Woomera, both in Australia; Canton Island; Hawaii; Point Arguello, Calif.; Guaymas, Mexico; White Sands, N. Mex.; Corpus Christi, Tex.; and Eglin AFB, Fla.
- **Scientific Satellite,** formerly called the Minitrack Net, consisting of 13 stations and extending around the world. Stations are located Blossom Point, Md.; Fort Myers, Fla.; Quito Ecuador; Lima, Peru; Antofagasta and Santiago, both in Chile; Woomera, Australia; Johannesburg, S. Africa; Goldstone Lake, Calif.; St. Johns, Newfoundland; East Grand Forks Minn.; Fairbanks, Alaska; and Winkfield, England.
- **Deep Space,** consisting of the three stations at Johannesburg, Woomera and Goldstone.

In addition, there are a number of ships and aircraft which can be moved to different spots all over the world to augment any of these tracking networks for a particular satellite mission. The U.S. Air Force also has portable systems consisting of a series of van-mounted trackers. These vans can be flown to almost any site on earth and, within several days, can be assembled to form a temporary station.

There also are individual pieces of tracking equipment — such as a command transmitter-antenna or an optical telescope — which can be transported to different areas around the Free World to provide coverage of a satellite at those critical times when the satellite might be beyond the reach of fixed-site stations. Finally, the Smithsonian Astro-

The Gen. H. H. Arnold, one of several ocean-going tracking ships used on the Eastern Test Range. Note the large radar antennas mid-ship.

physical Observatory maintains a world-wide net of telescopic cameras which are used to track and photograph satellites.

Missile Tracking

There are two major types of tracking systems in use today: radar and optics. There are two sub-divisions of radar — pulse and continuous-wave — and four major categories of optical systems — fixed cameras, cine-theodolites, ROTI (Recording Optical Tracking Instrument) and ballistic cameras.

Pulse Radar

Pulse radars, such as those manufactured by the Radio Corp. of America (RCA), send out small bursts of energy toward the missile or launch vehicle which they are tracking. These pulses strike a transponder on the vehicle, which then returns answering pulses. From the time difference between pulse transmittal and pulse return and the angular motions of the radar antenna, computers can calculate the position, altitude and direction of a vehicle.

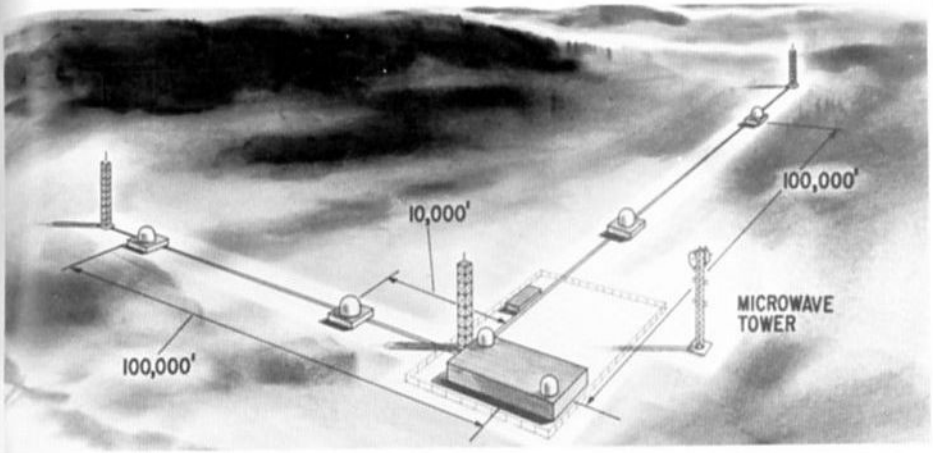
The later models of pulse radars used on the Eastern and Western ranges have the ability to bounce pulses directly off the side of a missile and track it in this manner, if the vehicle's transponder should fail. This auxiliary method of tracking is known as "skin tracking" and provides a greater measure of control over the vehicle than continuous-wave (CW) radars do.

Although not as accurate as CW systems pulse radars are considerably less expensive than CW units and require less ground area in which to be set up. There are seven such pulse radars, all RCA units, on the Atlantic range today and are spotted on different down-range stations so as to watch the entire powered phase of a missile's flight.

CW Systems

There are four continuous-wave systems used on the Eastern Test range today: Azusa, Glotrac (for GLObal TRACking), UDOP (for Ultra-high-frequency DOPpler) and Mistram (for MISsile TRAjectory Measuring system).

Cameras and other instrumentation fill the "green-house" built especially by the Air Force atop a C-135 jet plane (right). The plane flies down-range to monitor the re-entry of ICBM nose cones.



Locations of the GE-built MISTRAM sites had to be surveyed to thousandths of an inch so that the system could accurately pin-point the position in space of a missile.

All operate in the same basic way: a continuous, or unbroken, signal is transmitted from a central transmitter to the flying vehicle. A transponder on the vehicle receives the signal and, after changing the frequency slightly, returns it unbroken to several receiving sites.

Since some of these receiving sites are separated by as much as 100,000 feet (as the antennas of the Mistram system are), the returned signal will sound different to different sites. This difference — measured both in Dappler shift and phase shift of the signal — can be translated into position and velocity changes.

Mistram

The Mistram system, built by General Electric, is the newest and most accurate tracking system in the U.S. inventory. It can measure velocities to within 0.1 (1/10th) of a foot per second and distances to within six inches of actual values. Its five antenna sites — one central and two on each 100,000-foot long leg running out at right angles from the central transmitter-antenna — require considerable distance to lay out.

It is primarily for this reason that there are only two Mistram stations — one at Valkaria, 30 miles south of Cape Kennedy on the Florida mainland, and the other at Eleuthera, an island in the Bahamas slightly more than 100 miles east of Miami, Fla.

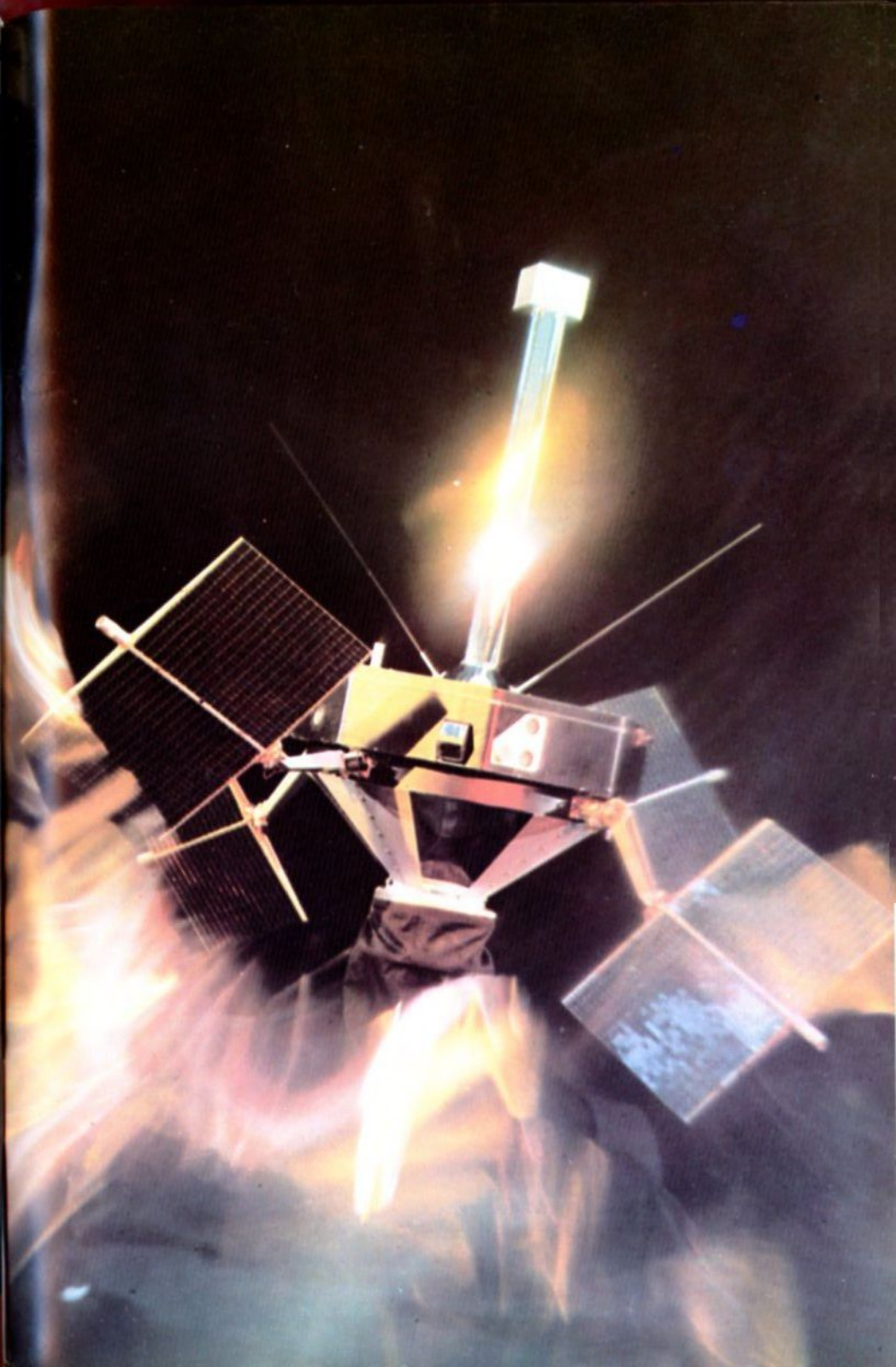
Azuza And Glotrac

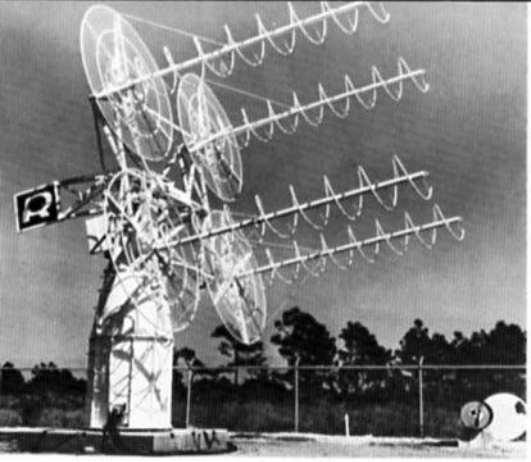
The Azusa and Glotrac systems are not quite as accurate as Mistram but require considerably less ground area and so can be set up on more down-range stations. Glotrac also has the virtue of being completely contained within a series of van-like trailers which can be easily transported around the world. UDOP compares with Azusa and Glotrac in accuracy and measures only the Doppler shift of a continuous signal transmitted by the flying vehicle.

If the radar tracking systems seem to be duplicating the work of radio-command guidance systems, it should be remembered that not all missiles and launch vehicles carry this type of guidance. Safety is best served by at least one system, independent of the flying vehicle, which can double-check the direction being given to that vehicle by its guidance system. The Air Force range safety officer at Cape Kennedy has at least two separate plots of a vehicle's flight trajectory to make certain that it does not wander off course and pose a threat to life or property.

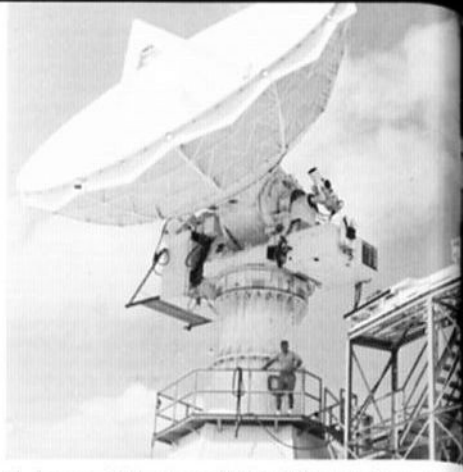
The circle of coverage of the first several stations on the Air Force Eastern Test Range slightly overlaps that of the station just up-range and that of the station immediately down-range of it, so that a vehicle is under constant surveillance during its most dangerous period — powered flight, when it has the propulsive power to wander off course and strike a populated area. But once the missile or launch vehicle has burned out, it will follow the strict laws of ballistics and (depending on its velocity at burn-out) either fly a predictable ballistic trajectory back to earth or an ascending arc into orbit.

One of the Explorer satellites





A command-tracker antenna built for the Telstar satellite.



A large dish-shaped tracking radar antenna down-range.

Range Safety

The data from all Eastern Test Range stations as far south as Antigua, some 1,300 miles southeast of the Cape, is fed into a computer back at Cape Kennedy. The computer constantly predicts where the vehicle now flying would land if its engines were stopped at that instant and displays this predicted impact point on a plotting board before the range safety officer. The board has a permanent map of the range etched on it so that the safety officer can tell at a glance whether the missile, if it should malfunction, would fall—in clear ocean, a shipping lane or an inhabited island He then can either hasten or delay the destruction of the vehicle to allow its harmless descent.

Destruction is achieved by sending a signal to an explosive package aboard the vehicle; this detonates and rips open the airframe of the vehicle. The range safety officer's job effectively is finished when the missile or launch vehicle burns out and is still on course — usually over the Antigua Island station.

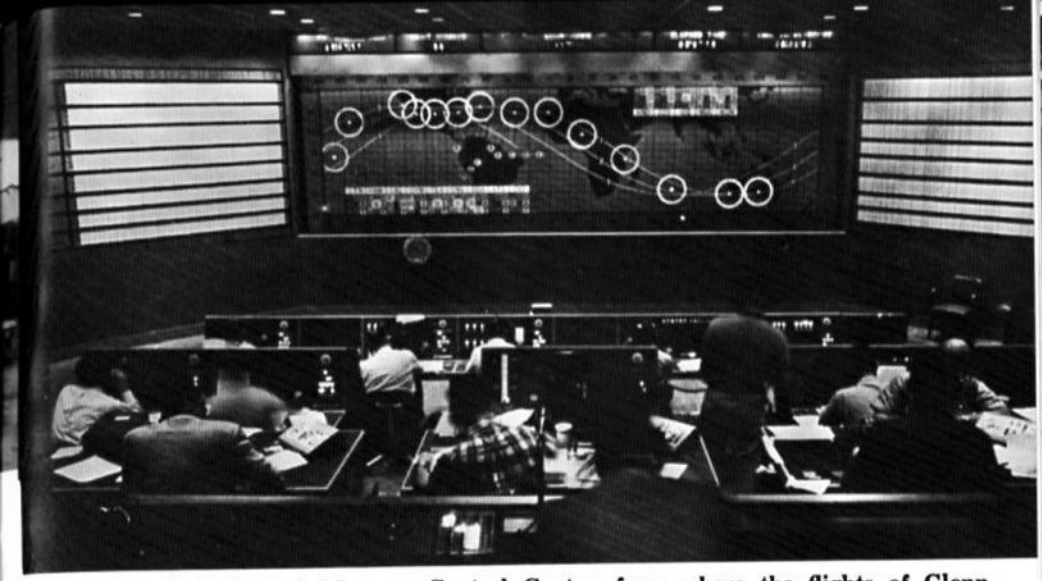
Such over-lapping coverage between one station and another obviously is needed during the boost phase of a missile's flight, but is not mandatory in the tracking of either scientific satellites or manned spacecraft. These space vehicles usually carry tape recorders to store their accumulated data until such time as they come within range of a tracking station, whereupon they dump it all over very rapidly — like a 33 rpm. phonograph record played at 78 rpm.

Where there is a requirement for tracking support of a particular satellite mission but where there is no land on which to establish even a temporary station the U.S. maintains a fleet of ships which can steam into the area and remain there for the duration of the mission.

Optical Tracking

The optical tracking systems include:

- **Fixed cameras** are positioned around the immediate launch area. Each is trained on a particular part of the first few thousand feet of the vehicle's trajectory and "sees" the vehicle only as it flies through that fixed region. Some of these cameras are as close as six feet to the missile's engines at the moment of lift-off and some are capable of exposing as many as 5,000 frames per second.
- **Cine-theodolites** are precise surveyor-like instruments which record on film the angles through which they had to turn to see the vehicle, the vehicle itself and a time reference (a Master Central Timing System at Cape Kennedy generates an electrical time signal to which every piece of range instrumentation — large or small — is synchronized to within millionths of a second).
- **ROTI** (see above) is a tracking telescope coupled with a 70-millimeter camera. With a 24-inch aperture and a variable focal length of 100- to 500-inches, ROTI cameras can take high-quality photographs at very long ranges.
- **Ballistic cameras** record either a series of flashing lights carried by the missile or the fiery streak of a missile's nose cone re-entering the earth's atmosphere. These cameras contain single negatives which are exposed during the



The dimly-lighted Mercury Control Center, from where the flights of Glenn, Carpenter, Schirra and Cooper were directed. When the capsule passed within range of a tracking station, the circle surrounding that station on the map at front lit up brightly.

several minutes of interest and the missile or its nose cone appears as a streak against a star background (which also explains why some missiles are launched at night).

The white line traced across the plate by the missile then can be measured very precisely against known star positions and its trajectory calculated as closely as man knows how. This trajectory then is compared to the one reported during the flight by the tracking systems and the vehicle's guidance system.

Ballistic camera data is used to check the accuracy of the fixed-position range tracking systems.

Lasers

Looking to the future, both the U.S. Air Force and the National Aeronautics and Space Administration are considering the possibilities of lasers* in tracking and/or communications systems.

A laser sends out an extremely narrow beam of light which disperses so little even over the longest distances that if one were trained on the moon from a ground-based station, it would throw a circle of light about 100 feet in diameter on that body — more than 230,000 miles away. This characteristic alone makes it attractive as a very accurate tracker, but in addition to this, a single beam can be so modulated as to carry more than 100 million separate telephone conversations.

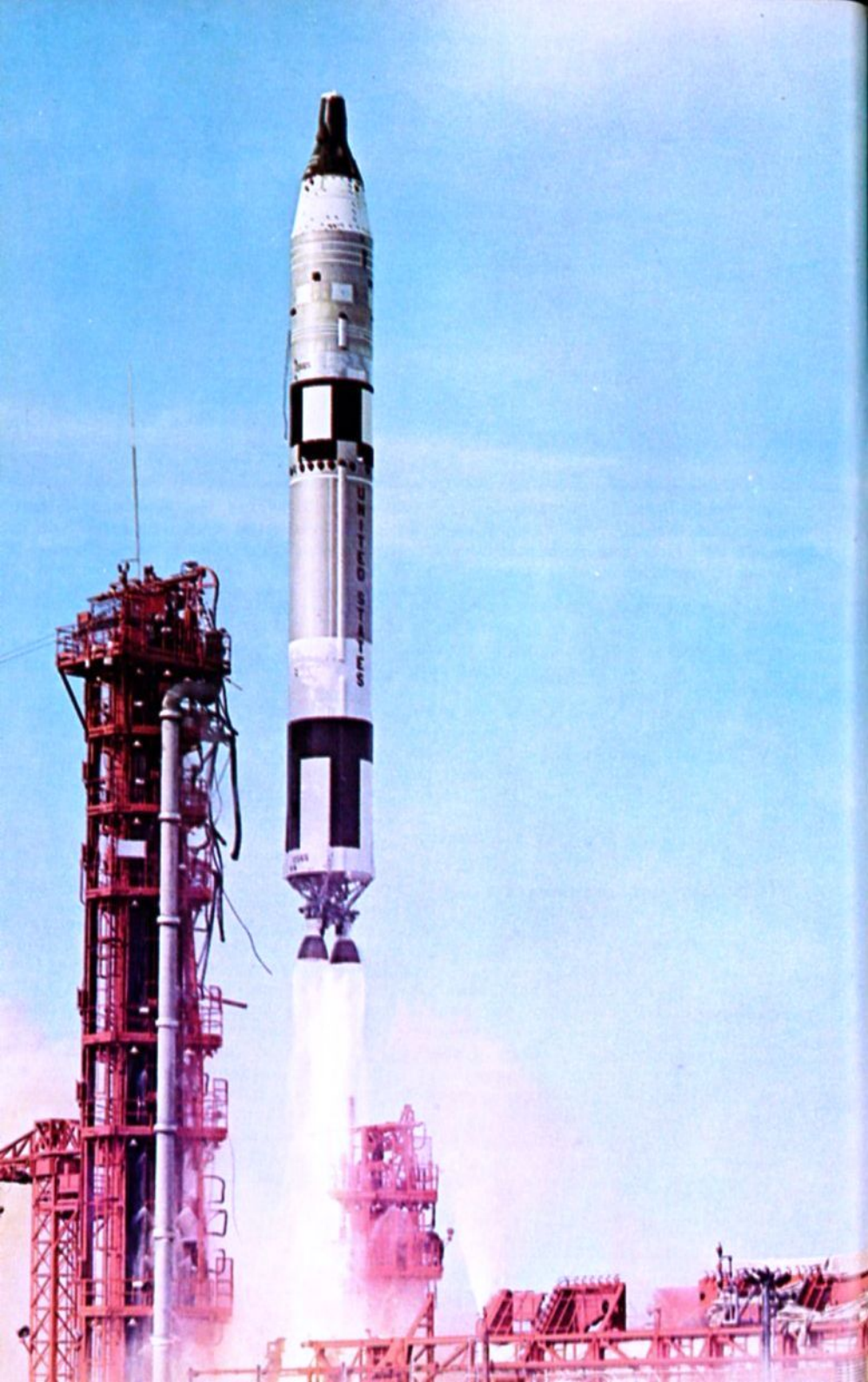
Using visible light as its working medium, however, a laser is susceptible to clouds, dust and haze just as flashlights and automobile headlights are. Still, the potential of lasers is so great that a number of firms and government laboratories are doing intensive research work aimed at maximizing their virtues and minimizing their drawbacks.

Telemetry Antennas

Alongside the radars and cameras at all but a few rare stations may be found the sometimes-small, sometimes-large, sometimes-odd-looking telemetry antennas. These antennas are the ear-phones of space communications.

Even more so than tracking radars, telemetry antennas come in a wide variety of sizes and shapes to satisfy particular requirements. There are the huge 85-foot diameter saucer-shaped parabolic antennas which are designed both to pull in the wide-band transmissions of some satellites (such as those with television cameras) and the weak signals of far-away deep-space

*Lasers (for Light Amplification by Stimulated Emission of Radiation) are devices which emit energy in the form of very powerful, very narrow beams of light when subjected to the pumping, or exciting, action of an external light source. A ruby rod will give out a highly collimated (parallel-sided), coherent (in phase) beam of red light when excited by the flashes of a very high-intensity xenon lamp. Today, many lasers use gas-filled tubes instead of solid rods as the light emission source.


SATURN

A giant 85-ft. diameter telemetry antenna used by the Air Force on both the Eastern and Western Test Ranges.

probes. There are the Yagi antennas, which resemble television aerials, and the helical antennas, which look like coil-wrapped rods protruding from small dish-shaped bases; these two types are used for satellites in low earth-orbit and for research and development missiles on ballistic flights.

Two Types of Antennas

Not all telemetry antennas have the ability to "track." Some are fixed and immobile—such as the Yagis—and satellites must fly into their listening range before their transmissions are picked up.

Other telemetry antennas, such as the helical and quad-helical, are used as "acquisition aids" since they are small and easy to swing around. With their 20-degree wide beams, they are able to sweep through large areas of the sky to find the target for narrow, 1-degree beam-width tracking radars.

Those stations tracking a satellite pass this information back to their network's control center,* where banks of computers use this data to calculate the future passes of that satellite. These predictions then are sent back out to the stations; they tell each station the precise direction from which the satellite can be expected to appear and exact time of appearance during the next 10 to 15 orbits.

With the fixed-antenna sites, the satellite must come to the stations — i.e., it must pass within the "look angle" of the antenna array in order to transmit its telemetry data.

Telemetry

What is telemetry? Basically, it is a form of communications. A telemetry system consists of both an airborne and ground-based segment. In the portion actually carried aboard the launch vehicle or satellite, there are the sensors, which are the data gatherers; the encoder, which puts the gathered data into a form suitable for radio transmission; and the transmitter which then sends it to the ground stations.

On the ground, there is the antenna, which receives the data; the processor, which decodes the transmitted code into electrical signals; and, finally, the data displays — the red and green lights, the dials, the recorders and the other indicators.

The telemetry system which Radiation, Inc., a major manufacturer in this area, is building for NASA's Apollo three-man spacecraft will send as many as 50,000 separate bits (pieces) of information on more than 400 spacecraft and astronaut functions and send it every second.

Some functions — such as the "on" or "off" position of a particular switch — might require only two bits to be reported. Other, more complex functions — such as an astronaut's heart beat — might require as many as 28 bits to describe just one contraction of that muscle.

And while all this information on the men and their spacecraft is showering down on ground stations, other telemetry systems on the three stages of the Saturn V launch vehicle will be sending down large quantities of data on the performance and status of all stages and their engines.

Telemetered Data

What is all this data and how important is it? First and foremost, it is information which either validates or repudiates the design of the missile, launch vehicle or satellite. Secondly, it can — and frequently does — tell the manufacturer of a faulty part what went wrong with the part (or sub-system, system or total vehicle) and how the fault should be corrected. Thirdly, it reports the findings of scientific satellites and/or the general condition of a team of astronauts.

*Cape Kennedy for the Atlantic Missile Range and the joint Atlantic and Pacific Ranges; the Goddard Space Flight Center for NASA's Scientific Satellite Net; the Manned Spacecraft Center for NASA's Manned Space Flight Net; and the Jet Propulsion Laboratory of the California Institute of Technology for the Deep Space Net.

Africans on camels throng around the NASA tracking station at Kano, Nigeria (left); Pan American and RCA employes live in apartments such as these (right) at the Antigua Island station on the Eastern Test Range.

Some of the data telemetered back to ground stations during the course of a flight is not of immediate importance to the men who must make decisions concerning the flight. This data can be stored on tapes until the flight has been completed; then it may be studied slowly and carefully.

The telemetered data that is of importance — such as an astronaut's pulse or the pressure inside an engine thrust chamber — is relayed from the ground station which received it back to the control center in "real-time."* Thus the men charged with the responsibility of making decisions have the freshest data on which to base their decisions.

A good percentage of the vital information telemetered to ground stations can be filtered at the control center to show only "out-of-tolerance" readings, i.e., those which deviate from a preplanned level.

For example, if the normal operating chamber pressure of an engine is 1,200 psi., reporting this value can be converted into electrical pulses which keep a small green bulb lit. But if the chamber pressure should fall below a certain level — perhaps 1,000 psi. — then the telemetry signals would be converted into pulses of different voltages which then would trigger a flashing red light. In this way, the test controller's attention would not be taken up by constantly monitoring perhaps hundreds of "OK" readings.

Pulse Code Modulation

Of the four types of radio-transmission techniques used in telemetry systems — FM / FM (frequency modulation / frequency modulation), PAM (pulse-amplitude modulation), PDM (pulse-duration modulation) and PCM (pulse-code modulation) — the last-mentioned is increasingly favored by space agencies and industries.

A PCM system converts the analog readings of the sensors into digital form while still aboard the satellite, launch vehicle or spacecraft and broadcasts this data as a series of coded pulses. The code may be thought of as strings of pulses, anywhere from four to 28 pulses to a string, arranged in meaningful patterns of "blips" (1's) and "blank's" (0's).

Since the ground station either does or does not receive a pulse — unlike some frequency-modulated transmissions, where continuous signals can get lost amid background static — PCM systems tend to be very accurate data transmitters. They also can move large quantities of data in short periods of time.

Data Processing

Once a ground antenna has received this wealth of data, it must be decoded and converted into electrical signals which will drive the appropriate displays.

This is called data processing and there are as many different techniques, approaches and equipments as there are

*An expression indicating that there is no appreciable time loss between the instant that an event takes place and the instant that it is displayed, in telemetered form, on a dial, light, oscilloscope or paper in the mission control center.

companies — from giants like RCA to medium-sized companies such as Radiation, Inc., and smaller firms such as Soroban Engineering, Inc., a specialist in punched-tape and punched-card systems.

The telemetry data from every vehicle is always stored on either magnetic or paper tape and usually winds up in voluminous printed reports, which are stored for future reference, study and/or analysis.

Ground communications links by which information is passed back and forth among stations are complex. One of NASA's communications networks, for example, comprises 102,000 miles of teletype circuits, 51,000 miles of telephone, 8,000 miles of high-speed data links and 12,000 miles of remote circuits.

Power Supplies

Satellites, manned spacecraft, launch vehicles, probes — in short, anything that flies into space require large or small amounts of electrical power to operate guidance systems, open valves, generate telemetry signals, run communications systems, etc. Generally, the power used by space vehicles is drawn from:

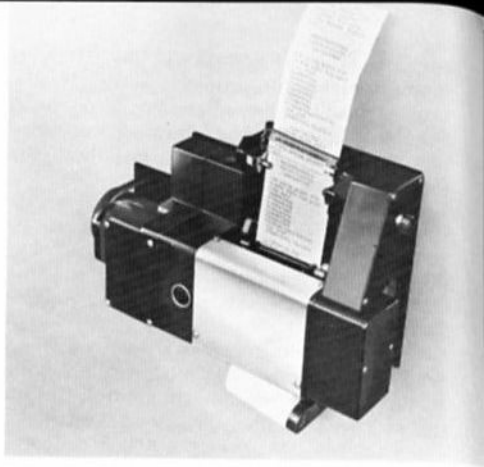
- **Chemical batteries,** which are similar in principle to the acid-and-lead plate automotive battery, but usually made of silver and zinc or nickel and cadmium to deliver far more power. They are used on space vehicles whose total "on" time is measured in days. These batteries usually are connected to solar cells (which are photovoltaic devices capable of converting sunlight directly into electrical energy) which re-charge them during "off" times.
- **Fuel cells** are devices which convert the energy of chemical reaction into electrical energy. They are more complex than batteries and require heavy tanks for their fuels, but are lighter in weight than a comparable quantity of batteries, and can provide power for missions of several weeks to several months duration. Further, such cells as the General Electric unit for the two-man Gemini spacecraft and the Pratt & Whitney system for the Apollo vehicle have the added virtue of distilling fresh, drinkable water as the product of reaction.
- **Nuclear batteries,** called SNAP for Systems for Nuclear Auxiliary Power, are considered the optimum power sources on the technological horizon today. Basically, SNAP units contain decaying radioisotope elements which generate great quantities of heat. Thermocouples attached to the outside of the isotope container then convert this heat into electricity.

Research is being conducted on even more exotic power systems. There are solar collectors, which are umbrella-shaped reflectors focusing sunlight on a mercury boiler; the mercury then expands through a turbine and drives a generator. There also are magnetohydrodynamic (MHD) generators, which are small rocket engines expelling a conductive gas through a magnetic field — the interaction of the two generates a current flow; and thermionic converters, which draw electrons from a material when that material is heated.

Environment Control Systems

While it might be supposed that only man-carrying spacecraft have environ-

Bell Telephone Laboratories built this horn-shaped antenna especially for the Telestar communications antenna. The antenna is covered with a radome to protect it against the weather.



Engineer works on a SNAP (Systems for Nuclear Auxiliary Power) electrical generator (left); a small, but high-speed printer (right) is typical of data displays used in space centers.

ment control systems to regulate the temperature, pressure and gas content within the capsule, the fact is that almost every satellite has some means of controlling its temperature and, as such, is considered to have an ECS. The heat generated by transmitters, batteries and servo-motors must be "dumped," as engineers say, in some way or the components eventually will deteriorate.

Heat-Rejection

There are several ways of achieving heat-rejection. Some satellites have a series of small shutters. A tube filled with a special fluid — such as a silicon ester — is snaked in and around all the heat-generating electronic equipment.

As the equipment heats up, so does the fluid in the tube; it expands and, since one end of the tube is connected to a small piston on the shutters, drives the louvers open. The heat then is radiated out into space.

Other satellites use "cold plates." These are hollow metal plates on which the electronic equipment is mounted. As the equipment operates and becomes warm, the heat soaks through the plate and into a liquid circulating through the hollow passages of the plate. The fluid then in turn expands, and moves through a radiator — usually the external skin of the satellite or spacecraft — where the heat is radiated into space.

Oxygen Conversion

Manned spacecraft have considerably more complex ECS units, simply because man must control more than just his temperature to survive. All three U.S. manned space flight programs — Mercury, Gemini and Apollo employ pure 100% oxygen environments at partial pressures of about 5 psi. compared to the normal 14 psi. level on the surface of the earth.

There are two major reasons for this, one medical and the other structural. First, the inhalation of pure oxygen prior to the start of a space flight and then all through the course of the flight eventually eliminates nitrogen from the pilot's blood and thereby precludes dysbarism, which is the sudden — and potentially fatal — formation of insoluble gas bubbles in the blood stream when pressure drops below one atmosphere (14 psi.). Oxygen does not form bubbles, but instead forms a chemical combination with the blood hemoglobin. Further, 100% pure oxygen also prevents hypoxia, which is oxygen starvation.

Structurally, which is the second reason for an all-oxygen environment at reduced pressures, we have seen, in the section of this chapter dealing with propulsion, that pressure-fed systems require heavier airframes to contain the higher pressure levels at which they operate. The same is true of manned spacecraft; if they carried a 14 psi. atmosphere, the structure would have to be significantly beefed up.

A heavier structure might have

scratched the Mercury program, since the minimal spacecraft which could safely be designed in 1958-1959 was just within the weight-lifting ability of our then-biggest launch vehicle — the Atlas ICBM. A heavier structure in the Gemini program might have made that spacecraft a one-man vehicle.

"Gas Loop"

The "gas loop" of all spacecraft is essentially the same. The pilot begins breathing oxygen from a reservoir stored within his craft. An exhaust system captures his exhaled breath and passes it — now carbon dioxide — through a series of chemical cylinders where the carbon atoms are trapped (these particular cylinders frequently are referred to as "CO^2 scrubbers") and converts it back to pure oxygen.

It then passes through charcoal to remove any odor and through a heat-exchanger (a device where heat is transferred from one medium to another — in this case, from the gaseous oxygen to water) to cool it.

Mixed with a small amount of fresh oxygen drawn from the reservoir, the gas then is ducted back into the pilot's suit and circulated over his body in a cooling flow before passing into his helmet, where he breathes it.

In the Mercury program, astronauts had to remain in their suits at all times during a flight. The cooling loop was not always efficient and the tightness of the form-fitting suit made for some uncomfortable moments, especially during the longer flights of Walter Schirra and Gordon Cooper.

"Shirtsleeve" Conditions

As a result, NASA engineers decided to build a "shirt-sleeve" environment in the Gemini and Apollo spacecraft where the pilots could remove their space suits and work almost in as much comfort as a modern-day office worker.

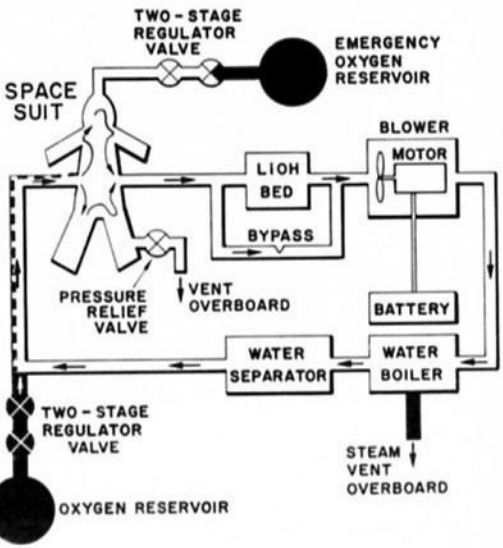
In the two-man Gemini spacecraft, the crew members will be able to remove their helmets, their gloves and part of their sleeves, and their boots almost up to their knees. They will breathe, and be cooled by, the oxygen flowing through the cabin interior. In the Apollo vehicle, the astronauts will be able to remove their suits completely and will work in soft, long underwear-like garments.

Orbital Mechanics

Although the Space Age has been with us for most of a decade now, many engineers and scientists who work on various space programs are continually surprised to find themselves asked by relatives and acquaintances: "What keeps a satellite up?"

The answer is: "A balancing of velocity and gravity." Perhaps the best way to illustrate the relationship between velocity and gravity is to imagine what happens to a bullet fired from a gun. The bullet leaves the gun barrel at a very high speed and travels straight ahead until gravity pulls it to the ground. But if a little more force is added to that same bullet, it would be shot from the gun at a higher muzzle velocity and therefore travel a greater distance before falling.

With ever-higher speeds, the bullets would travel ever-greater distances. Finally, it can be seen that if a sufficiently high velocity could be imparted to the bullet, it would travel completely around the world before falling to the ground. Such a bullet would have made one orbit of the earth.



Schematic shows the flow of oxygen through an astronaut's space suit. Besides breathing it, the pilot also uses it to cool his body.

This is the basic space-suit to be worn by Apollo astronauts when they fly to the moon in this decade.

Launch Velocity Factor

Essentially, this is what keeps a satellite up. A rocket-powered launch vehicle imparts a tremendous velocity to a satellite — on the order of 17,500-18,000 miles per hour. Since it is flying at an altitude — usually above 100 miles — where there is practically no atmosphere, there is nothing to affect the satellite except the pull of gravity. Gravity does its best to pull the satellite to the ground and, in fact, the satellite does fall toward the earth's surface. But because of its great speed, the "falling" satellite continually over-shoots the earth and so remains in orbit.

Once in orbit, the satellite travels around the earth as if inside a track or ring. The line along which the satellite flies is called the "orbital plane" and, for all intents and purposes, this does not vary once the satellite is in space. Every orbit has these distinguishing elements:

- **Perigee.** It is the lowest point of an orbit relative to the earth's surface and is the closest a satellite comes to the earth. It also is the point at which the satellite was injected into orbit.
- **Apogee.** This is the highest point of the orbit. An easy way to remember which is which is to associate the word "atop" with apogee; apogee is above perigee.
- **Period.** This is the time a satellite requires to fly around the world, starting at one point and then returning over that same point.
- **Inclination.** The orbital plane of a satellite intersects the earth's equator at some definite angle and this is called the angle of inclination. In this connection, it might also be pointed out that every orbital plane must pass through the center of the earth. A small, off-set orbit circling only around the North Pole is impossible.

Three Types of Orbit

If a satellite's apogee and perigee are the same, its orbit is said to be circular. Any orbit other than circular is said to be elliptical, or egg-shaped. All satellites first enter an elliptical orbit and "transfer" to a circular path by adding velocity to the spacecraft at apogee point; this frequently is achieved by a small solid-propellant motor called an "apogee-kick" motor.

It is possible, although it has not yet been done, to make the orbital plane of a satellite co-incide with the equator;

this is an "equatorial" orbit. If the period of such a satellite is 24 hr., it will be synchronized with any point on earth — which also takes 24 hr. to complete a revolution about its axis. Thus, a satellite in an equatorial, synchonous orbit will appear to be stationary above a certain point on earth — when actually it is merely spinning around the earth in perfect coordination with that point on earth.

A satellite can be put in a synchronous orbit inclined to the equator. But as the earth rotates on its tilted axis beneath the satellite, the satellite will appear to trace out a figure-8 pattern.

Satellites also can be flown in polar orbits, which are inclined 90 deg. to the equator. In polar orbit, a satellite circles both poles, while the earth rotates beneath it. Military reconnaissance satellites usually are placed in polar orbit, because they eventually fly over every part of the earth during the course of their lifetime in space.

Satellites seemingly have the ability to change their direction in space — coming out of the northwest and heading toward the southeast of the U.S. on one orbit and coming out of the southeast and bound for the northwest on the next pass. As with so many puzzling aspects of orbital mechanics the apparent contradiction is attributable to the rotation of the earth.

Rendezvous In Space

Rendezvous — a technique upon which so much of America's success in space depends — is defined as bringing one space vehicle to within close range of another at some point in space.

This may sound simple, but when one considers all the factors involved in just one satellite's orbit and then recognizes that rendezvous is the precise matching of a second satellite's orbital factors to the first, the scope of the problem becomes more apparent.

There are two key differences between the orbits of two satellites which must be resolved before rendezvous can take place:

• **The angle of inclination** of each should be within 2 or 3 deg. of each other — in other words, if satellite-A has an angular inclination of 30 deg. to the equator, satellite-B (when launched) should be aimed for an inclination of no more than 32 or 33 deg. Why? If both satellites have identical apogees and perigees, but different inclinations, then

When walking on the lunar surface, the astronaut will wear this white outer garment as a protection against both the extreme temperatures on the lunar surface and cosmic dust particles bombarding the moon.

The two Americans who will explore the moon will carry backpacks like this model. The pack contains breathing/cooling oxygen, water and communications gear.

one might be reaching apogee over Australia while the other is flying through perigee somewhere over the Atlantic Ocean. Despite the fact that the two satellites might have identical apogees, perigees and periods, they might wind up always half-a-world apart if their inclinations were different.

Why is the angle so small? Because the momentum of a satellite travelling at 17,500-18,000 mph. is extremely great and it cannot make large deviations from its flight path, just as an automobile moving at 90 mph. cannot make a right-angle turn.

The Target and The Seeker

Once one satellite is in orbit (the first one in space usually is called the "target"), the second (called the "seeker") can use the propulsive thrust of its launch vehicle during powered flight to change its bearing slightly so that its final orbital plane coincides with that of the target vehicle.

If the seeker vehicle did not have this plane-change ability, then the only time the second vehicle could be launched would be those few-and-far-between split-seconds when the planes of both vehicles coincided. By having this corrective ability, the seeker now has a "launch window"—a time span in which it can be fired — of as much as 20 to 40 minutes, instead of a second or two.

• **The phase difference** of each should be such that the two vehicles catch up with each other within a reasonable time period — "reasonable" usually considered as two days or less.

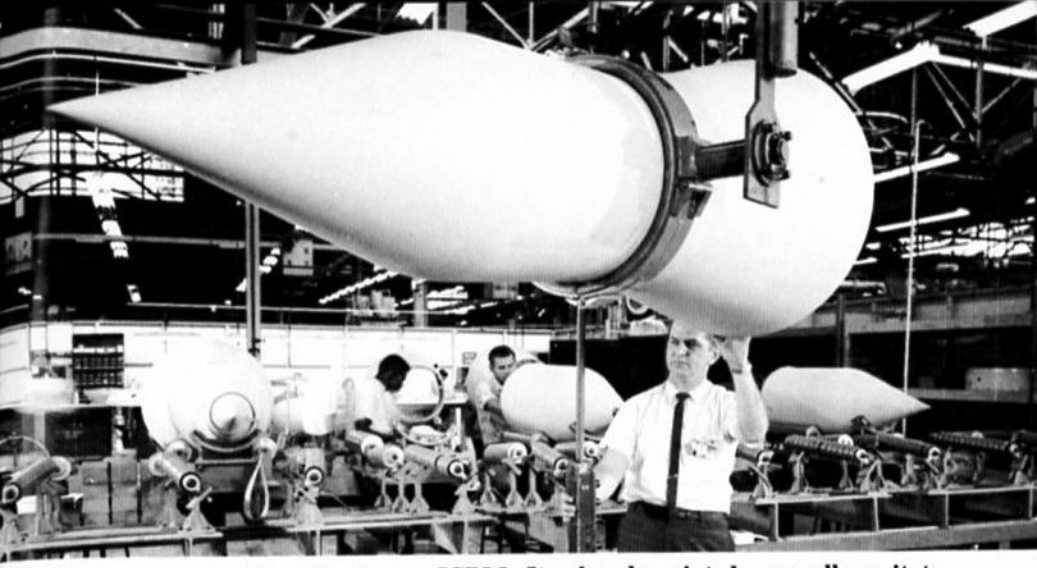
Assuming that both target and seeker now are in the same orbital plane, phase then is their relation to each other within that plane. If the target vehicle passes overhead of the launch stand just as the seeker is launched, the two are said to be 360 deg. out of phase. If the target is half-way around the world from the launch stand at the instant that the seeker is launched, they are 180 deg. out of phase.

For most rendezvous missions to be attempted in earth orbit by the U.S., 150 deg. is about the maximum phase difference which will be allowable.

Difficulties in Achieving

In many respects, the resolution of phase differences between two satellites is a harder problem than out-of-plane errors.

Picture this analogy: two jet liners are to fly across the United States together. One takes off from New York



A nose cone for the Minuteman ICBM. Its sharply-pointed nose allows it to plunge back to earth at very fast speeds.

and heads for Los Angeles. The second aircraft takes off from Chicago and must rendezvous with the New York plane before they then fly together to Los Angeles. Thus, he must take off while the New York aircraft is just approaching Chicago, so that by the time he has climbed to altitude, the N. Y. aircraft will appear off his wing.

Since correcting the phase difference between target and seeker on the very first orbit of both spacecraft would require a split-second time of launch for the second vehicle, a way has been devised to provide a little more elbow-room in the launch window: one spacecraft is placed in a circular orbit and the other in an elliptical orbit; both vehicles have the same inclination and the same apogee, but their periods differ by as much as 5 min.

Thus, it takes the target vehicle in its larger circular orbit more time to go around the world than the seeker spacecraft in its smaller, elliptical orbit. If it takes the target 98 min. in which to complete one orbit and the seeker only 93 min., then the latter gains 5 min. on the former every orbit. Eventually, therefore, if both have the same apogee, there must come a time when they both fly through that point in space at the same time — and rendezvous can be accomplished

Docking Technique

If, after rendezvousing, the two spacecraft physically touch each other and are joined together, they are said to have "docked." Trying to join two objects together which are moving at speeds of 18,000 mph. might seem a frightening task, but it should be remembered that the only speed which they really see is the relative difference between themselves. Keeping this difference down to 1 fps. or less, the two can be brought together as softly as two feathers.

The virtue of the rendezvous-and-docking technique is that it allows the assembly of a segmented vehicle in space, the total weight of which is far greater than that which could be lifted by any single launch vehicle.

One final word about satellies, orbits, gravity and velocity: as the speed of a satellite increases, the more it will tend to elude the grip of gravity. At speeds of 25,000 mph., a satellite is travelling too fast for the earth's gravity to affect it any longer and so it flies off into space. This speed is called "escape" velocity and a probe must be moving at least this fast if it is to travel out into the uncharted sea of deep space.

Re-entry

The earth's atmosphere — that gaseous blanket of oxygen, nitrogen, carbon dioxide, and water vapor which surround the earth — extends upward to an altitude of no more than 150-200 mi. Quite dense on the earth's surface, the atmosphere begins to thin out above 20,000 ft.

A nose cone puts on a fireworks display in the dark evening sky as it re-enters the atmosphere. The cone is the leading white streak; the other streaks are the disintegrating fragments of the missile which boosted the nose cone.

Above 100 mi. altitude, the gas particles are very few and far between. A satellite speeding around the earth at 18,000 mph. will, however, strike these particles and lose some minute part of its kinetic energy (the energy of motion) in the collision. After a great many of these collisions, the satellite will have lost so much of its energy that it will no longer be travelling at 17,500-18,000 mph. and therefore will be unable to sustain orbit.

It is indicative of how far apart these particles are that some satellites will remain aloft for several centuries before enough collisions have occurred to trip them and they fall back to earth.

Falling back to earth — or "re-entry," as the phenomenon is called — is no simple matter. For one thing, the satellite might not have sufficient velocity to remain in orbit, but it still is doing between 16,000 and 10,000 mph. as it reenters the earth's atmosphere.

Tremendous Friction

Plunging into ever-denser layers of the atmosphere at these speeds, the satellite encounters tremendous friction in colliding with the closely-packed air molecules. This friction generates extremely high temperatures and the thin stainless steel or aluminum structures of the satellites eventually and literally burn up.

The nose cones of all ballistic missiles and some satellites are designed to withstand these severe heat loads in one of two ways:

• **Heat-sink,** in which the payload is hidden behind a blunt shield of a material such as copper or graphite. The heat soaks slowly through the thick shield and is distributed evenly over the surface and depth of the shield. The bluntness of the shield also comes in handy; it creates a shock-wave in front of the spacecraft which prevents more air from striking the face of the shield.

A heat-sink shield was used on some Mercury capsules and on the early nose cones of America's ICBM force.

• **Ablation,** in which controlled amounts of the satellite's external coating are permitted to vaporize and flow off, carrying heat with it.

Ablation materials, such as those built by the General Electric Co. and Avco Corp. — the two recognized giants in this particular sphere of space technology, can be fabricated to vaporize or melt at any specific temperature desired by the spacecraft builder. Materials are synthetic compounds which are applied to the surface of the structure while still in a plastic, pliable condition and allowed to "cure" on the structure.

Ablation-type materials can take more heating than heat-sinks and so are preferred by engineers today; they either can be used for vehicles with high reentry speeds — such as nuclear nose cones — or for the same protection at less weight for other satellites — such as manned capsule — than a heat-sink shield.

This brief explanation of the technology underlying space has been designed to give the layman a better appreciation of the programs which he is supporting through his tax dollars. If it also encourages youngsters to consider a career in space science or engineering, then it will more than have served its purpose.

DATA TABLES

U.S. Missiles, Launch Vehicles and Spacecraft

Major U.S. Missiles

Type	Name	Length in feet	Diameter in feet	Weight at Launch-Lbs.	Thrust in lbs.	Guidance System	Approx Range (Mi.)
Surface-to-surface Missiles	Atlas D	82.5	10.0	265,000	300,000	Radio-inertial	9,000
	Atlas E	82.5	10.0	270,000	330,000	Inertial	9,000
	Atlas F	82.5	10.0	269,000	330,000 57,000	Inertial	9,000
	Mace B	44.0	4.5	14,000	5,200	Inertial	1,200+
	Minuteman	53.7	6	65,000	260,000	Inertial	6,300
	Minuteman	55.9	6	65,000		Inertial	6,300
	Minuteman	59.8	6	65,000		Inertial	6,300
	Polaris A1	28.0	4.5	28,000		Inertial	1,200
	Polaris A2	31.0	4.5	30,000		Inertial	1,500
	Polaris A3	31.7	4.5	30,000		Inertial	2,500
	Titan I	98.0	10.0	220,000	300,000 80,000	Radio-inertial	6,300
	Titan 2	103.0	10.0	330,000	430,000 100,000	Inertial	6,300
Guided Missiles	Pershing	34.6	3.3	10,000		Inertial	400
	Redstone	69.0	6.0	61,700	78,000	Inertial	20
	Bomarc B	45.0	3.0	16,000	24,000	Active homing radar	400

Major U.S. Launch Vehicles

Name	Agency Using	Stages	Thrust (1,000 lbs.)	Diameter in feet	Height in feet	Weight at Launch (1,000 lbs.)	Payload for 300 mi. orbit (1,000 lbs.)	Payload for Earth escape (1,000 lbs.)
Atlas	USAF/NASA	1/2	300	10	72	260	33	
		1	67					
Saturn I	NASA	1	1,500	21.6	125	1,120	20	
		2	90					
Saturn IB	NASA	1	1,500	21.6	141	1,250	28.5	7
		2	200					
		3						
Saturn V	NASA	1	7,500	33	275	6,034	220	90
		2	1,000					
		3	200					
Scout	NASA	1	86	3.3	72	38	0.240	
	USAF	1a	103					
		2	64					
		3	23					
		4	3					
		4a	5					
Thrust Augmented Delta (TAD)	NASA	1	170	8				
		2	7.7	8	27		.5	.06
		3	2.8					
		1	162				1.0	.12
Titun II	USAF/NASA	1	430	10	90	300	8	
		2	100					
Titan IIIA	USAF	1	430	10	120	n.a.	5	
		2	100					
		3	16					
Titan IIIC	USAF	1	2,500	30	120	n.a.	25	5.1
		2	430					
		3	100					
		4	16					
UPPER STAGES Agena B	USAF/NASA	2	15	6	25			
Agena D	USAF	2		6				
Centaur	NASA	2	30	10	8.5	2.3		
Ablestar	USAF/NASA	2	7.87	4.5	15.8	10.0	660-AMR 340-PMR	

Major U.S. Spacecraft

Type	Name	Agency Using	Weight in lbs.	Launch Vehicle	Date of First Launch
MANNED	Apollo	NASA	90,000	Saturn 5	1969
	LM	NASA	24,000	Saturn 5	1965
	Apollo station (study)	NASA		Saturn 1B	
	Gemini A	NASA	7,200	Titan 2	Spring, 1964
	Gemini B	USAF	6,000	Titan 3	1966
	MORL (study)	NASA	15,000	Saturn 1B	
Special Uses	Advanced Technology	NASA	650	Atlas Agena	1967
	Commercial Comsat	ComSat Corp.	100	TAD	1965
	Echo 2	NASA	770	Thor Agena	1/25/64
	Gemini Target	NASA	5,000	Atlas D	1965
	Nimbus	NASA	650	Thor Agena	Spring, 1964
	Relay	NASA	172	Thor Delta	12/16/62
	Telstar	Commercial	170	Thor Delta	7/10/62
	Tiros	NASA	285	Thor Delta	4/1/60
	Tiros	Weather Bureau	285	Augmented Delta	Summer, 1964
	Transit	USN	175	Thor Ablestar	4/13/60
Planetary	Lunar Orbiter	NASA	800	Atlas Agena	1965
	Mariner (Mars)	NASA	570	Atlas Agena	1964
	Mariner (Venus/Mars)	NASA	1,200	Centaur	1966
	Pioneer (Quiet Sun Year)	NASA	115	Thor Delta	1965
		NASA	804	Atlas Agena	8/23/61
	Surveyor Lander	NASA	2,100	Centaur	1965
Scientific	Observatories	NASA			
	Astronomical		3,600	Atlas Agena	1965
	Geophysical		1,000	Thor/Atlas Agena	Fall, 1964
	Solar		490	Thor Delta	3/7/62
	Advanced Solar		900	Atlas Agena	1968
	Explorers	NASA			2/1/58
	Air Density (AD)		130	Scout	12/19/63
	Beacon (S-66)		126	Thor Delta	11/27/63
	Energetic Particles (S-3)		100	Thor Delta	10/2/62
	Ionosphere (S-48)		110	Scout	1964
	Monitoring Platform (IMP)		135	Thor Delta	11/27/63

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GLOSSARY

Important Space terminology not covered in the text

Ablation—The removal of surface material from a nose cone or spacecraft by vaporization, or melting, during high-speed movement through atmosphere to provide thermal protection to the underlying structure.

Abort—To cancel or cut short a flight.

Accelerometer — An instrument which measures acceleration or gravitational forces capable of imparting acceleration.

Acquisition—The process of locating the orbit of a satellite or trajectory of a space probe so that tracking or telemetry data can be gathered.

Active—Transmitting a signal, as "active satellite," in contrast to "passive."

Aerodynamic Vehicle—A device, such as an airplane, glider, etc., capable of flight only within a sensible atmosphere and relying on aerodynamic forces to maintain flight.

Afterbody—A companion body that trails a satellite or nose cone.

Anomaly—In general, a deviation from the norm.

Antigravity—A hypothetical effect that would arise from some energy field's cancellation of the effect of the gravitational field of the earth or other body.

Aphelion—That orbital point farthest from the sun when the sun is the center of attraction. That point nearest the sun is called "perihelion."

Apogee—In an orbit about the earth, the point at which the satellite is farthest from the earth.

Artificial Gravity—A simulated gravity established within a space vehicle, as by rotating a cabin about an axis of a spacecraft, the centrifugal force generated being similar to the force of gravity.

Astronomical Unit (abbr AU)—In the astronomical system of measures, a unit of length usually defined as the distance from the Earth to the Sun.

Atmospheric Drag—The retarding force produced on a satellite by its passage through the gas of the high atmosphere.

Attenuation—In physics, any process in which the flux density (or power, amplitude, intensity, illuminance, etc.) of a "parallel beam" of energy decreases with increasing distance from the energy source.

Attitude—The position or orientation of an aircraft, spacecraft, etc., either in motion or at rest, as determined by the relationship between its axes and some reference line or plane such as the horizon.

Ballistic Trajectory—The trajectory followed by a body being acted upon only by gravitational forces and the resistance of the medium through which it passes.

Bird—A colloquial term for a rocket, satellite, or spacecraft.

Black Box—Colloquially, any unit, usually an electronic device such as an amplifier, which can be mounted in a rocket, spacecraft, or the like as a single package.

Blackout—A fadeout of radio communications due to environmental factors such as ionospheric disturbances, or a plasma sheath surrounding a reentry vehicle. 2. A condition in which vision is temporarily obscured by a blackness, accompanied by a dullness of certain of the other senses, brought on by decreased blood pressure in the head and a consequent lack of oxygen, as may occur in pulling out of a high-speed dive in an airplane.

Blockhouse—(Also written "block house"). A reinforced concrete structure, often built underground or partly underground, and sometimes dome-shaped, to provide protection against blast, heat, or explosion during rocket launchings or related activities; specifically, such a structure at a launch site that houses electronic control instruments used in launching a rocket.

Boiloff—The vaporization of a cold propellant such as liquid oxygen or liquid hydrogen, as the temperature of the propellant mass rises as in the tank of a rocket being readied for launch.

Booster Engine—An engine, especially a booster rocket, that adds its thrust to

the sustainer engine.

Braking Ellipses—A series of ellipses, decreasing in size due to aerodynamic drag, followed by a spacecraft in entering a planetary atmosphere.

In theory, this maneuver will allow a spacecraft to dissipate energy through aerodynamic heating without burning up.

Burn—A period during which a rocket engine is firing, as in "second burn" the second period during a flight in which the engine is firing.

Burnout—An act or instance of the end of fuel and oxidizer burning in a rocket; the time at which this burnout occurs. Compare cutoff.

Checkout—A sequence of actions taken to test or examine a thing as to its readiness for incorporation into a new phase of use, or for the performance of its intended function.

Chemical Rocket—A rocket using chemical fuel, fuel which requires an oxidizer for combustion, such as liquid or solid rocket fuel.

Closed Ecological System—A system that provides for the maintenance of life in an isolated living chamber such as a spacecraft cabin.

Coherent—Of electromagnetic radiation, being in phase so that waves at various points in space act in unison.

Companion Body—A nose cone, last-stage rocket, or other body that orbits along with an earth satellite.

Complex—Entire area of launch site facilities. This includes blockhouse, launch pad, gantry, etc. Also referred to as a "launch complex."

Component—A self-contained combination of parts and/or assemblies within a subsystem performing a function necessary to the subsystem's operation. Examples are: receivers, transmitters, modulators, etc.

Console—An array of controls and indicators for the monitoring and control of a particular sequence of actions, as in the checkout of a rocket, a countdown action, or a launch procedure.

Control Rocket—A vernier engine, retrorocket, or other such rocket, used to guide or make small changes in the velocity of a rocket, spacecraft, or the like.

Countdown—The time period in which a sequence of events is carried out to launch a rocket; the sequence of events.

Cryogenic Propellant—A rocket fuel, oxidizer, or propulsion fluid which is liquid only at very low temperatures.

Cutoff—An act or instance of shutting something off; specifically in rocketry, an act of instance of shutting off the propellant flow in a rocket, or of stopping the combustion of the propellant.

Data Reduction—Transformation of observed values into useful, ordered, or simplified information.

Deep Space Net—A combination of three radar and communications stations in the United States, Australia, and South Africa so located as to keep a spacecraft in deep space under observation at all times.

Deep Space Probes—Spacecraft designed for exploring space to the vicinity of the moon and beyond. Deep space probes with specific missions may be referred to as "lunar probe," "Mars probe," "solar probe," etc.

Degradation — Gradual deterioration in performance.

Decay — Deterioration of a satellite's orbit.

Destruct—The deliberate action of destroying a rocket vehicle after it has been launched, but before it has completed its course.

Destructs are executed when the rocket gets off its plotted course or functions in a way so as to become a hazard.

Dish—A parabolic type of radio or radar antenna, roughly the shape of a soup bowl.

Docking—The process of bringing two spacecraft together while in space.

Drogue Parachute—A type of parachute attached to a body, used to slow it down; also called "deceleration parachute," or "drag parachute."

Ecliptic—The apparent annual path of the sun among the stars; the intersection of the plane of the earth's orbit with the celestial sphere.

Escape Velocity—The radial speed which a particle or larger body must attain in order to escape from the gravitational field of a planet or star.

Exhaust Velocity—The speed at which the exhaust gases are expelled from the nozzle of a rocket.

Exotic Fuel—Any fuel considered to be unusual, as a boron-based fuel.

Explosive Bolt—A bolt incorporating an explosive which can be detonated on

command, thus destroying the bolt. Explosive bolts are used, for example, in separating a satellite from a rocket.

Eyeballs In, Eyeballs Out—Terminology used by test pilots to describe the acceleration experienced by the person being accelerated. Thus the acceleration experienced by an astronaut at lift-off is "eyeballs in" (positive g in terms of vehicle acceleration), and the acceleration experienced when retrorockets fire is "eyeballs out" (negative g in terms of vehicle acceleration.)

Fatigue—A weakening or deterioration of metal or other material, or of a member, occurring under load, especially under repeated, cyclic, or continued loading.

Free Fall—1. The fall or drop of a body, such as a rocket not guided, nor under thrust, and not retarded by a parachute or other braking device. 2. Weightlessness.

g or G—An acceleration equal to the acceleration of gravity, approximately 32.2 feet per second per second at sea level; used as a unit of stress measurement for bodies undergoing acceleration.

Gantry—A frame structure that spans over something, as an elevated platform that runs astride a work area, supported by wheels on each side; specifically, short for "gantry crane" or "gantry scaffold."

Garbage—Miscellaneous objects in orbit, usually material ejected or broken away from a launch vehicle or satellite.

Geophysics—The physics of the earth and its environment, i.e., earth, air, and (by extension), space.

GOX—Gaseous oxygen.

Ground Support Equipment (GSE) — Any ground-based equipment used for launch, checkout, or in-flight support of a space project.

Guidance—The process of directing the movements of an aeronautical vehicle or space vehicle, with particular reference to the selection of a flight path.

Gyro—A device which utilizes the angular momentum of a spinning rotar to sense angular motion of its base about one or two axes at right angles to the spin axis. Also called "gyroscope."

Hold—During a countdown: To halt the sequence of events until an impediment has been removed so that the countdown can be resumed, as in "T minus 40 and holding."

Injection—1. The introduction of fuel, fuel and air, fuel and oxidizer, water, or other substance into an engine induction system or combustion chamber. 2. The process of putting an artificial satellite into orbit. 3. The time following launching when non-gravitational forces (thrust, lift, and drag) become negligible in their effect on the trajectory of a space vehicle.

More than one injection is possible in a single flight if engines are stopped and restarted.

Insertion—The process of putting an artificial satellite into orbit. Also the time of such action.

Interface—The junction points or the points within or between systems or subsystems where matching or accommodation must be properly achieved in order to make their operation compatible with the successful operation of all other functional entities in the space vehicle and its ground support.

Ionosphere—The atmospheric shell characterized by a high ion density. Its base is at about 70 or 80 km and it extends to an indefinite height.

Launch Pad—The load-bearing base or platform from which a rocket vehicle is launched. Usually called "pad."

Launch Ring—The metal ring on the launch pad on which a missile stands before launch.

Launch Vehicle—Any device which propels and guides a spacecraft into orbit about the earth or into a trajectory to another celestial body: Often called "booster."

Launch Window—An interval of time during which a rocket can be launched to accomplish a particular purpose as "lift-off occurred 5 minutes after the beginning of the 82-minute launch window."

Lift-off—The action of a rocket vehicle as it separates from its launch pad in a vertical ascent.

Light Year—The distance light travels in one year at rate of 186,000 miles per second (300,000 kilometers per second.) Equal to 5.9×10^{12} miles. See PARSEC.))

LOX—1. Liquid oxygen. Used attributively as in "LOX tank," "LOX unit." Also called "loxygen." 2. To load the fuel tanks of a rocket vehicle with

liquid oxygen. Hence, "loxing."

Mach Number — (After Ernst Mach 1838-1916), Austrian scientist.) A number expressing the ratio of the speed of a body or of a point on a body with respect to the surrounding air or other fluid, or the speed of a flow, to the speed of sound in the medium; the speed represented by this number.

Magnitude—Relative brightness of a celestial body. The smaller the magnitude number, the brighter the body.

Maser—An amplifier utilizing the principle of microwave amplification by stimulated emission of radiation. Emission of energy stored in a molecular or atomic system by a microwave power supply is stimulated by the input signal.

Missile—Any object thrown, dropped, fired, launched, or otherwise projected with the purpose of striking a target. Short for "ballistic missile," "guided missile."

Mock-Up—A full-sized replica or dummy of something, such as a spacecraft, often made of some substitute material, such as wood, and sometimes incorporating functioning pieces of equipment, such as engines.

Module—1. A self-contained unit of a launch vehicle or spacecraft which serves as a building block for the overall structure. The module is usually designated by its primary function as "command module," "lunar landing module," etc. 2. A one-package assembly of functionally associated electronic parts; usually a plug-in unit.

Orbit—1. The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves. 2. To go around the earth or other body in an orbit.

Oxidizer—Specifically, a substance (not necessarily containing oxygen) that supports the combustion of a fuel or propellant.

Passive—Reflecting a signal without transmission, as "Echo is a passive satellite." Contrasted with "active."

Payload—1. Originally, the revenue-producing portion of an aircraft's load, e.g., passengers, cargo, mail, etc. 2. By extension, that which an aircraft, rocket, or the like carries over and above what is necessary for the operation of the vehicle during its flight.

Perigee—That orbital point nearest the earth when the earth is the center of attraction.

Perihelion—For an elliptic orbit about the sun, the point closest to the sun.

Period—The interval needed to complete a cycle. Often used in reference to time of complete orbit.

Pickoff—A sensing device, used in combination with a gyroscope in an automatic pilot or other automatic or robot apparatus, that responds to angular movement to create a signal or to effect some type of control.

Pitchover—The programmed turn from the vertical that a rocket under power takes as it describes an arc and points in a direction other than vertical.

Plasma Sheath—1. The boundary layer of charged particles between a plasma and its surrounding walls, electrodes, or other plasmas.

Pod—An enclosure, housing, or detachable container of some kind, as: (a) an engine pod, (b) an ejection capsule.

Posigrade Rocket—An auxiliary rocket which fires in the direction in which the vehicle is pointed, used for example in separating two stages of a vehicle.

Pressure Suit—A garmet designed to provide the human body an environment above ambient pressure so that respiratory and circulatory functions may continue normally, or nearly so, under low-pressure conditions, such as occur at high altitudes or in space without benefit of a pressurized cabin.

Probe—Any device inserted in an environment for the purpose of obtaining information about the environment. Specifically, an instrumented vehicle moving through the upper atmosphere or space or landing upon another celestial body in order to obtain information about the specific environment.

Prototype—Spacecraft or element thereof which is under-going or has passed environmental and other tests which qualify design for fabrication of flight units or elements thereof.

Purge—To rid a line or tank of residual fluid, especially of fuel or oxygen in the tanks or lines of a rocket after a test firing or simulated test firing.

Radiation Belts — See VAN ALLEN BELTS, MAGNETOSPHERE.

Recovery—The procedure or action that

obtains when the whole of a satellite, or a satellite instrumentation package, or other part of a rocket vehicle is recovered after a launch; the result of this procedure.

Recycle—In a countdown: To stop the count and to return to an earlier point in the countdown.

Red Shift—In astronomy, the displacement of observed spectral lines toward the longer wavelengths of the red end of the spectrum. Compare **space reddening.**

The "red shift" in the spectrum of distant galaxies has been interpreted as evidence that the universe is expanding.

Retrorocket — (From 'retroacting'.) A rocket fitted on or in a spacecraft, satellite or the like to produce thrust opposed to forward motion.

Scrub—To cancel a scheduled rocket firing, either before or during countdown.

Sensor—The component of an instrument that converts an input signal into a quantity which is measured by another part of the instrument. Also called "sensing element."

Shot—An act or instance of firing a rocket, especially for the earth's surface, as "the shot carried the rocket 200 miles."

Shroud—The nosecone of a space vehicle when it is used only as a shield for passage through the atmosphere from launch to orbit. It is usually jettisoned when orbital speed is achieved.

Solar Cell—A photovoltaic device that converts sunlight directly into electrical energy.

Solar Flare—Sudden local increase in the intensity of the light of hydrogen on the sun. Some solar flares are associated with the expulsion of charged particles and the production of radio bursts.

Stage—A propulsion unit of a rocket, especially one unit of a multistage rocket, including its own fuel and tanks.

Stage-and-a-Half—A liquid-rocket propulsion unit of which only part falls away from the rocket vehicle during flight, as in the case of booster rockets falling away to leave the sustainer engine to consume remaining fuel.

Sustainer Engine—An engine that maintains the velocity of a missile rocket vehicle once it has achieved its programmed velocity by use of booster or other engine.

Thrust—1. The pushing force developed by an aircraft engine or a rocket engine. 2. Specifically, in rocketry, the product of propellant mass flow rate and exhaust velocity relative to the vehicle.

Tracking—The process of following the movement of a satellite or rocket by radar, radio, and photographic observations.

Transfer Orbit—In interplanetary travel an elliptical trajectory tangent to the orbits of both the departure planet and the target planet.

Translunar—Of or pertaining to space outside the moon's orbit about the earth.

T-Time—Any specific time, minus or plus, as referenced to "zero," or "launch" time, during a countdown sequence that is intended to result in the firing of a rocket propulsion unit that launches a rocket vehicle or missile.

Ullage—The amount that a container, such as a fuel tank, lacks of being full.

Umbilical Cord—Any of the servicing electrical or fluid lines between the ground or a tower and an upright rocket missile or vehicle before the launch. Often shortened to 'umbilical.'

Van Allen Belt, Van Allen Radiation Belt—[For James A. Van Allen, 1915-.] The zone of high-intensity radiation surrounding the earth beginning at altitudes of approximately 1000 kilometers.

Weightlessness—A condition in which no acceleration, whether of gravity or other force, can be detected by an observer within the system in question.

Zero G = Weightlessness.

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